Japanese Experiment Module (JEM) Berthing Evaluation

13th May 2011

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Japan Aerospace Exploration Agency (JAXA)

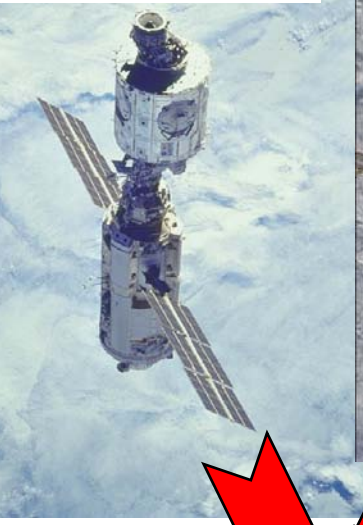
Outline

1. Japanese Experiment Module ’Kibo’
2. Assembly Sequences of JEM
3. Berthing Operation Consideration of EF, ES
4. Initial Checkout of JEMRMS
5. Berthing Operation by JEMRMS

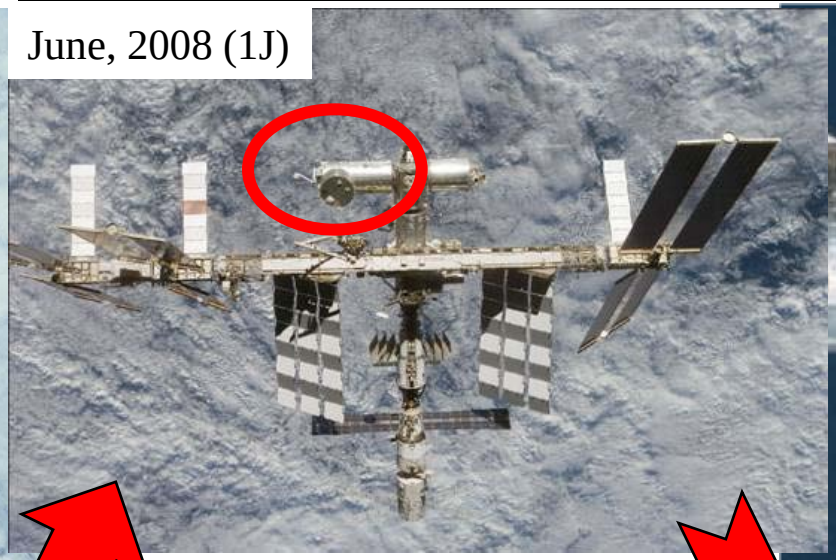
Japanese Experiment Module

International Space Station

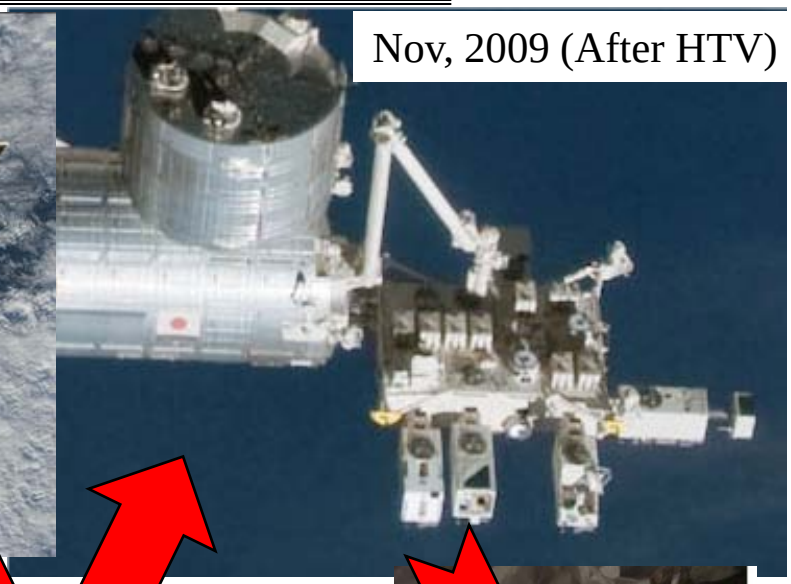
December, 1998
Start Assembly



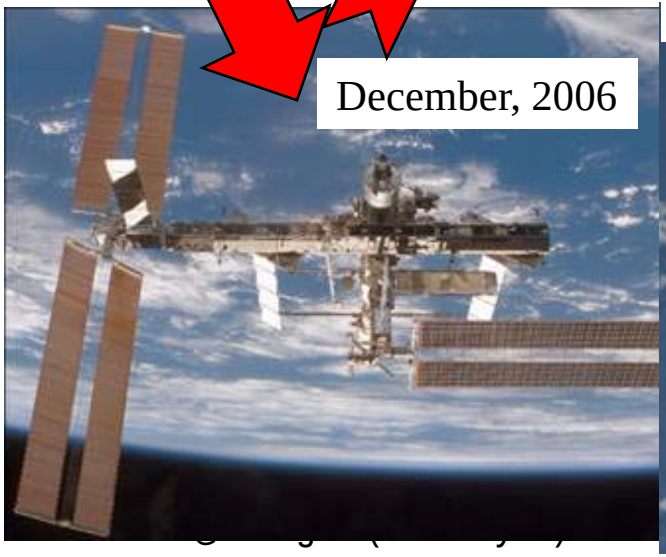
June, 2008 (1J)



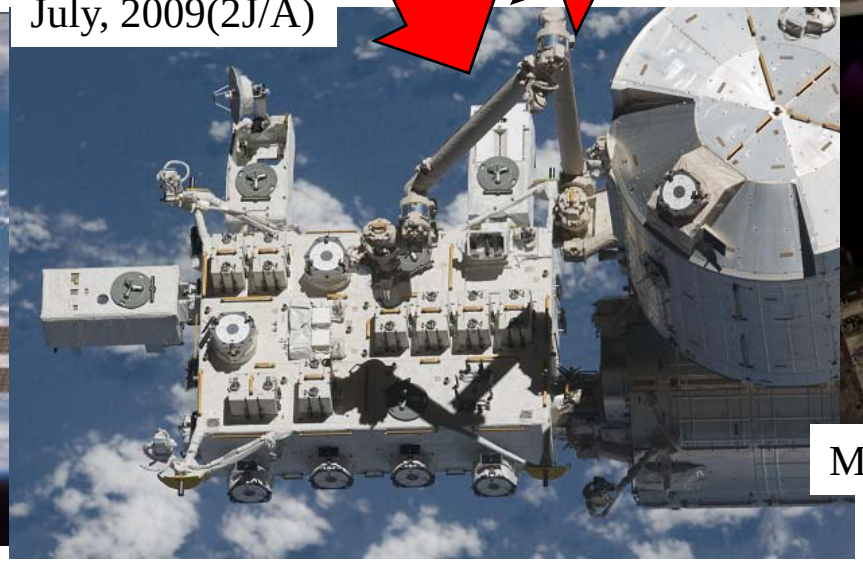
Nov, 2009 (After HTV)



December, 2006



July, 2009(2J/A)

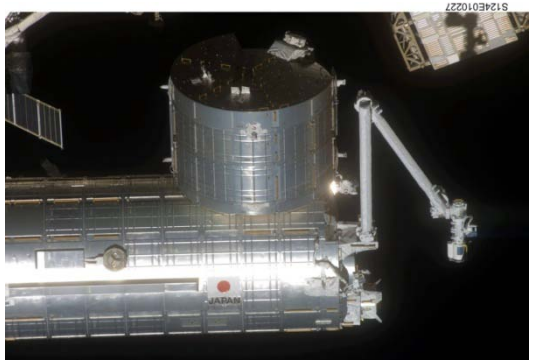


March, 2010(SFA Inst)

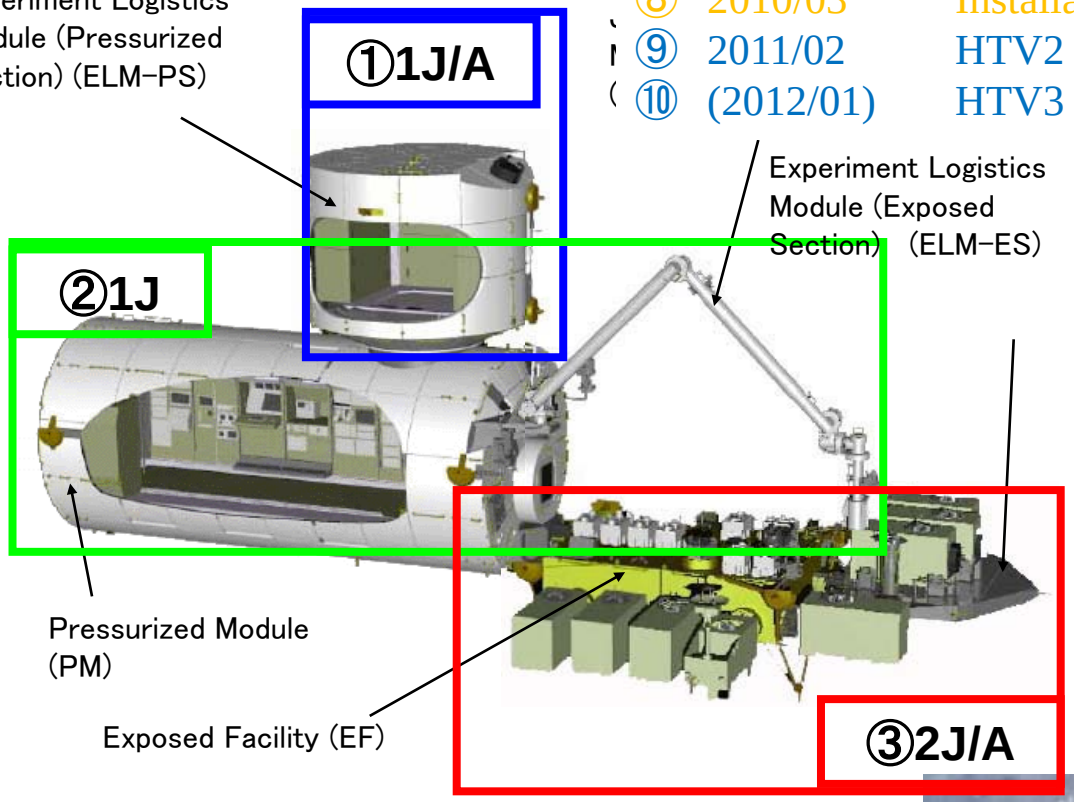
by courtesy of NASA

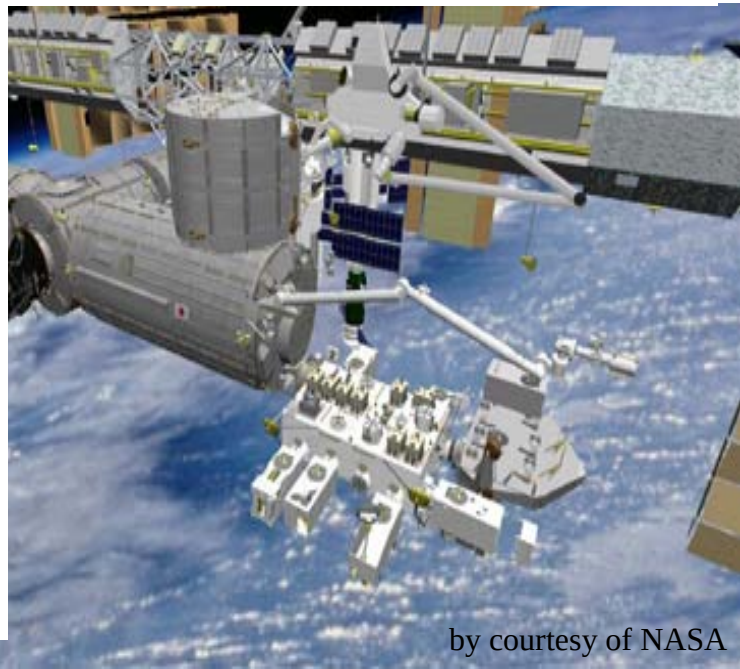
Japanese Experiment Module

Japanese Experiment Module 'Kibo' Assembly & Maintenance Events



①	2008/03	1J/A	ELM-PS:ELM Pressurized Section
②	2008/06	1J	PM:Pressurized Module & JEMRMS
③	2008/06	Relocation	ELM-PS:
④	2009/07	2J/A	EF:Exposed Facility
⑤	2009/07	2J/A	ELM-ES:ELM Exposed Section
⑥	2009/07	2J/A	Payloads(3)
⑦	2009/09	HTV1	HTV-EP, Payloads(2), (SFA)
⑧	2010/03	Installation	JEMRMS SFA(Small Fine Arm)
⑨	2011/02	HTV2	HTV-EP2,
⑩	(2012/01)	HTV3	HTV-EP3, Payload(1)

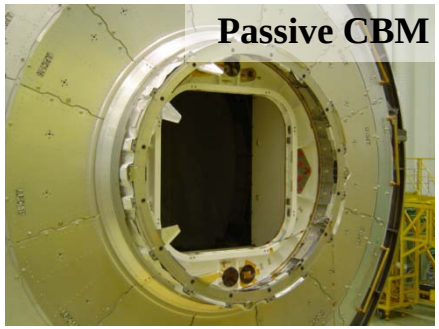


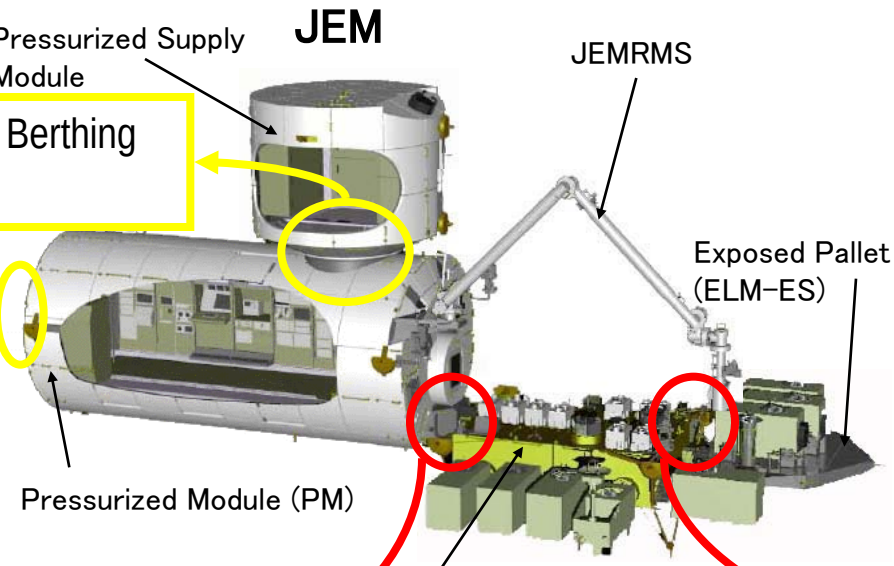


by courtesy of NASA

Japanese Experiment Module

JEM Berthing Mechanism





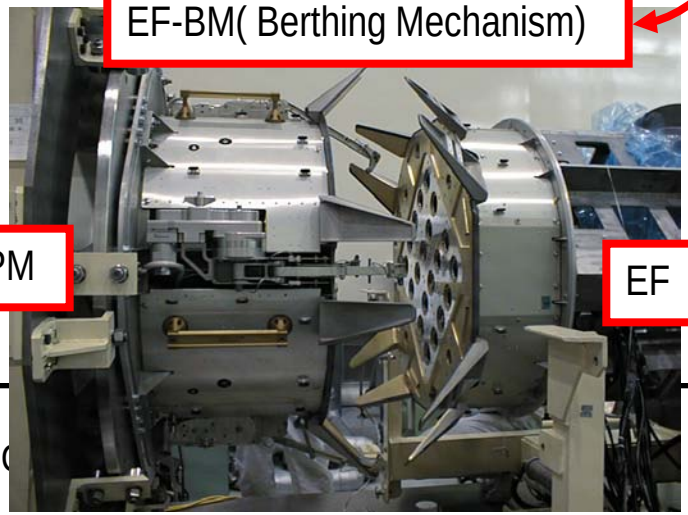
CBM(Common Berthing Mechanism)

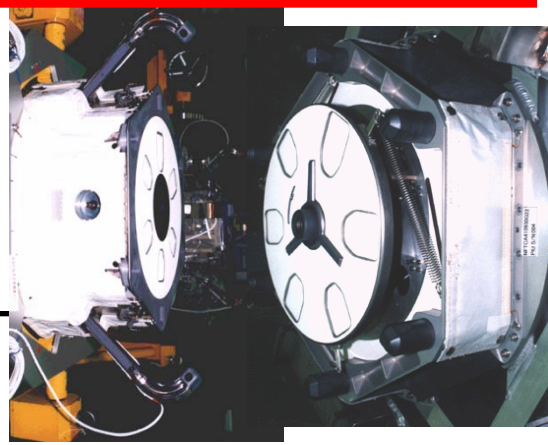
②1J

EF-BM(Berthing Mechanism)

EEU (Exposed Exchange Unit)

③2J/A



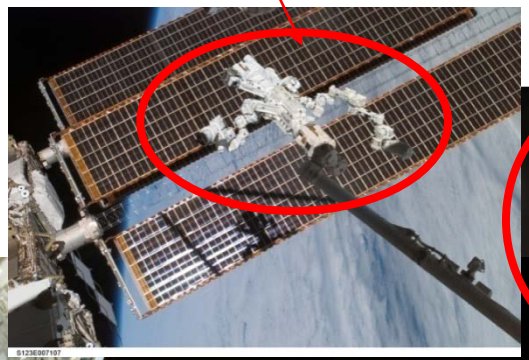


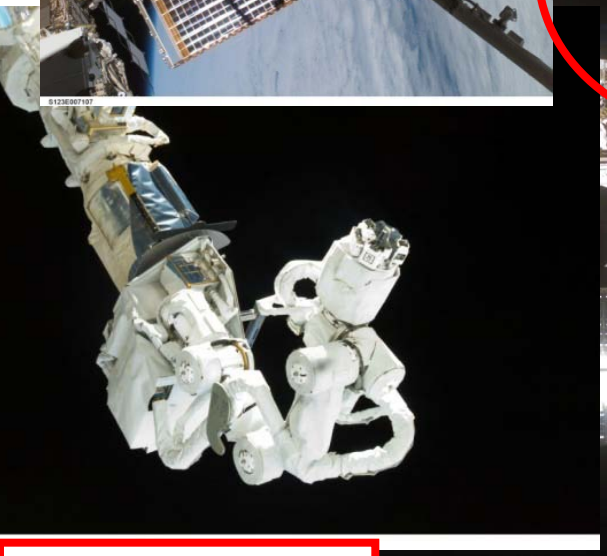
JEM Mechanism is unique

Japanese Experiment Module

Robot Arms Utilized for Kibo Assembly

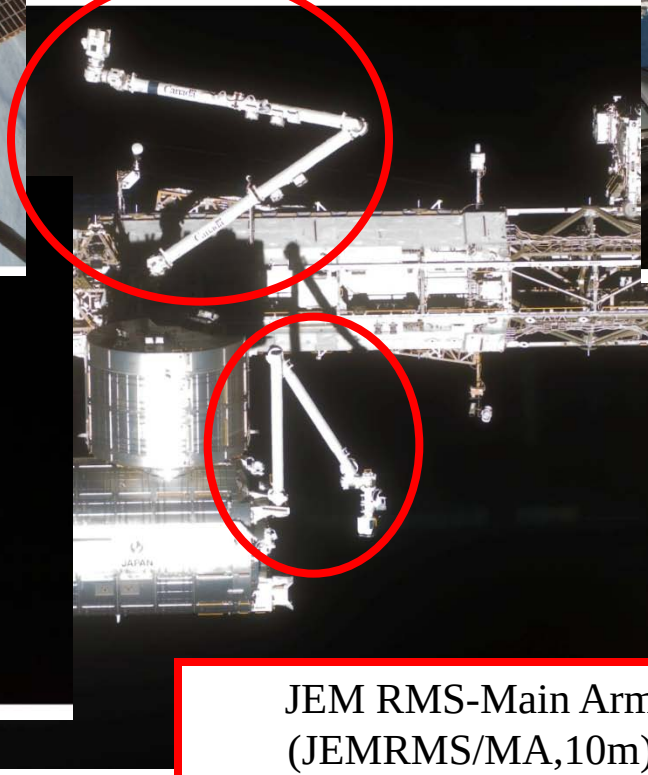
DEXTRE(SPDM)





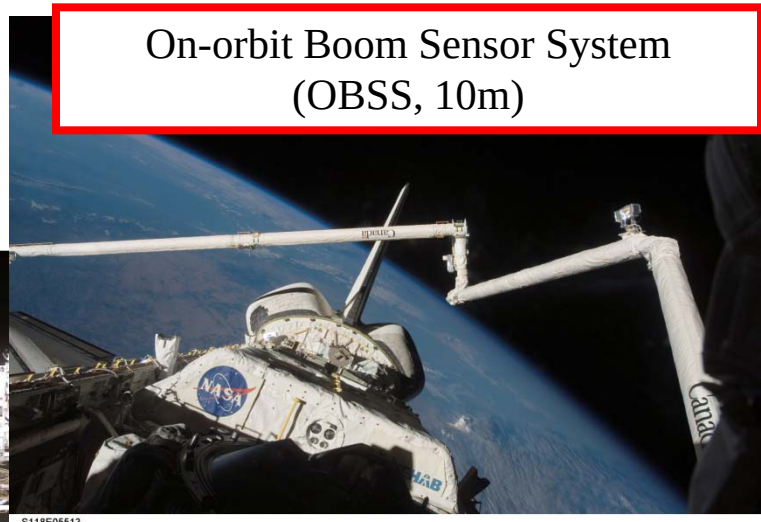
JEMRS Small Fine Arm (SFA,2m)

Space Staion RMS (SSRMS,17m)



JEM RMS-Main Arm (JEMRMS/MA,10m)

On-orbit Boom Sensor System (OBSS, 10m)



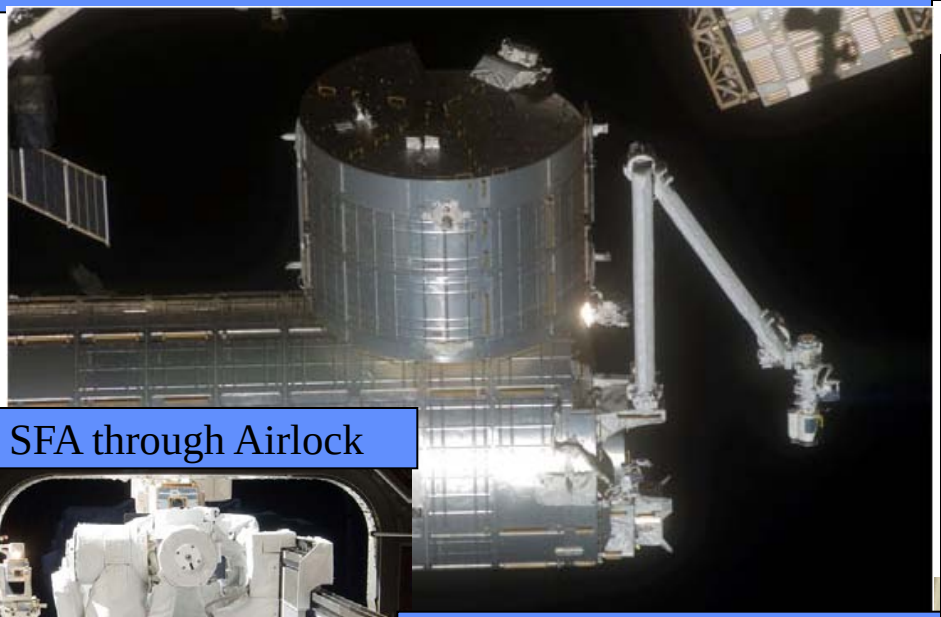
Shuttle RMS (SRMS,15m)

by courtesy of NASA

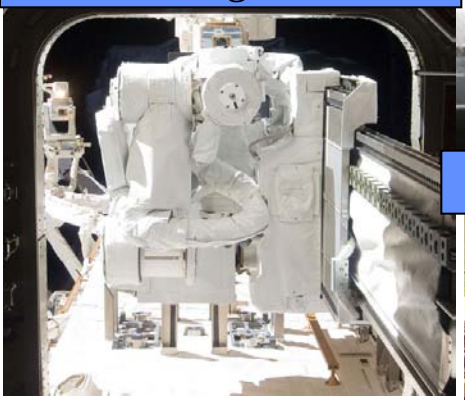
Japanese Experiment Module

JEM Remote Manipulator System (JEMRMS)

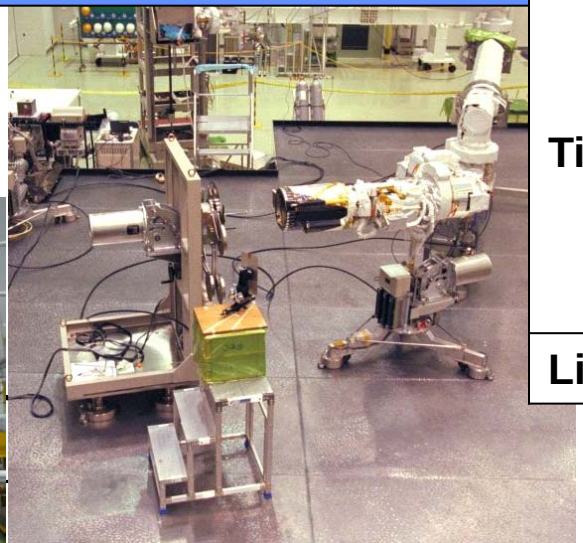
Main Arm on orbit



SFA through Airlock



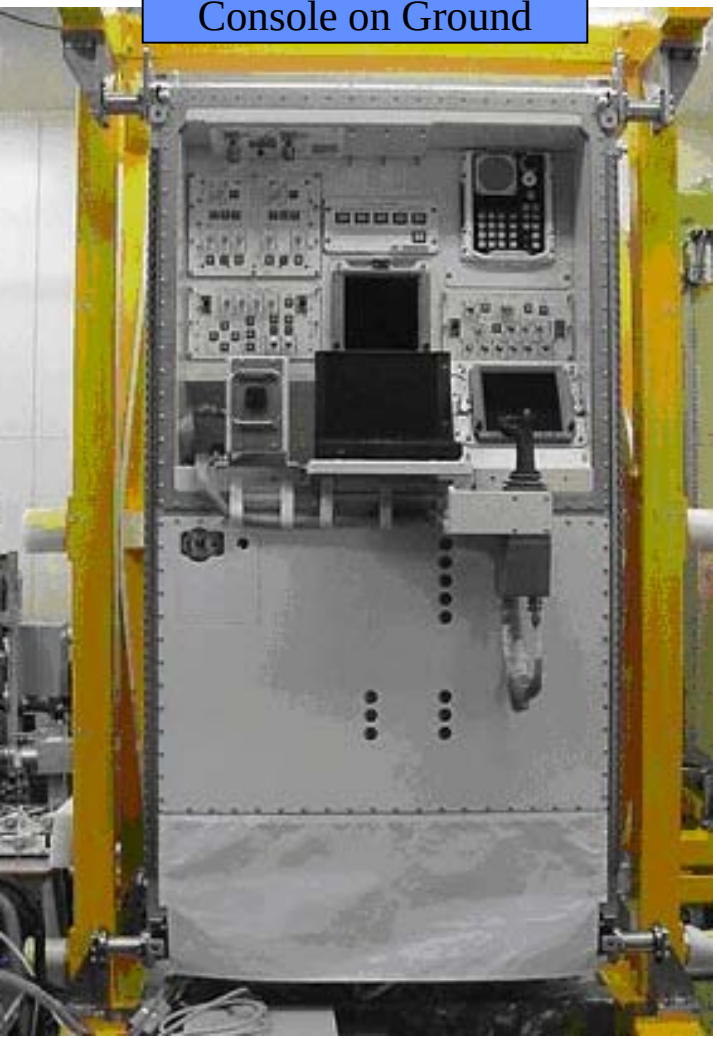
Main Arm on ground test



Type	Main Arm (MA)	Small Fine Arm (SFA)
DOF	6	6
Lenght	Aprox. 9.9m	Aprox. 1.9m
Weight	780kg	200kg
Payload Mass	Max 7,000kg	Max 300kg
Pstn. Accura.	±50mm	±10mm
	±1deg	±1deg
Tip Vel.	60mm/s (P/L: <600kg)	50mm/s (P/L: <80kg)
	30mm/s (P/L: <3,000kg)	25mm/s (P/L: <300kg)
	20mm/s (P/L: <7,000kg)	-
Life	10years or more	

JEMRMS Console

Console on Ground



Console on orbit

by courtesy of NASA

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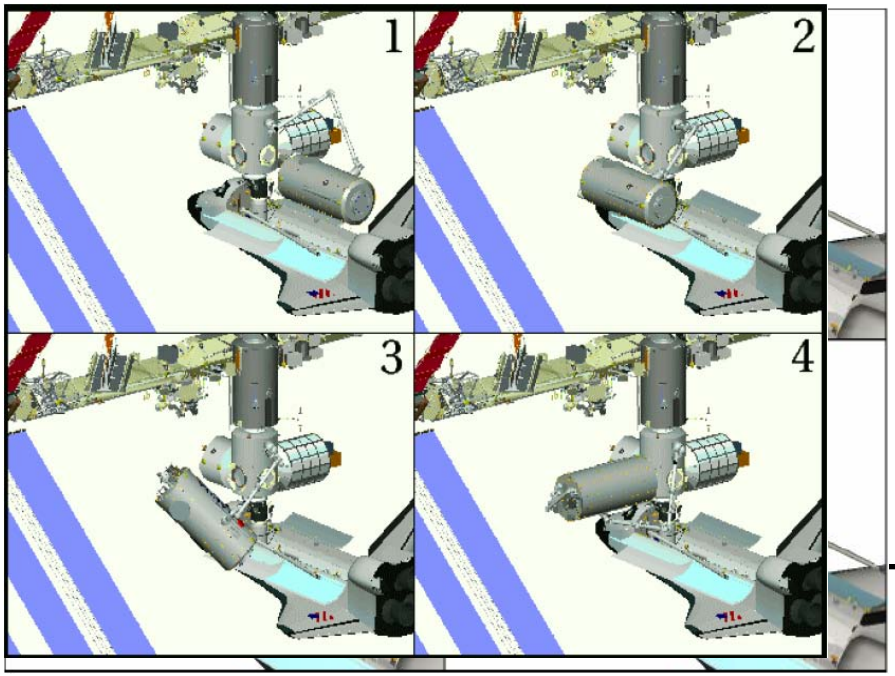
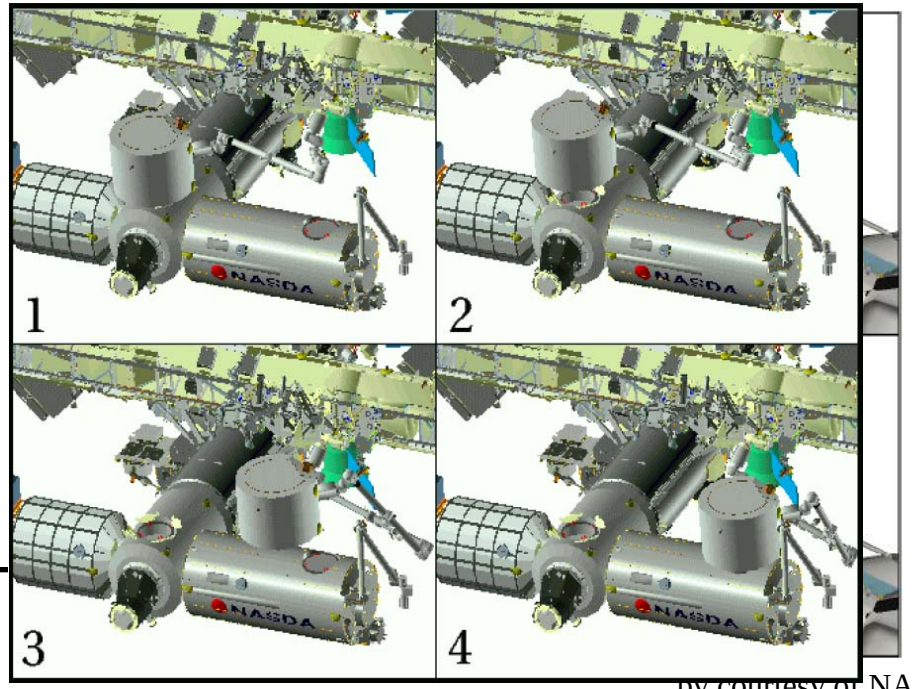
Japanese Experiment Module

Assembly Sequences of ELM-PS and PM

Flight 1J/A	Attach ELM-PS to NODE2 Zenith (CBM) by SRMS
Flight 1J	Attach PM to NODE2 Port (CBM) by SSRMS
	Attach ELM-PS to PM Zenith (CBM) by SSRMS
	Deploy JEMRMS Main Arm
Stage 1J	JEMRMS On-orbit Checkout





by courtesy of NASA

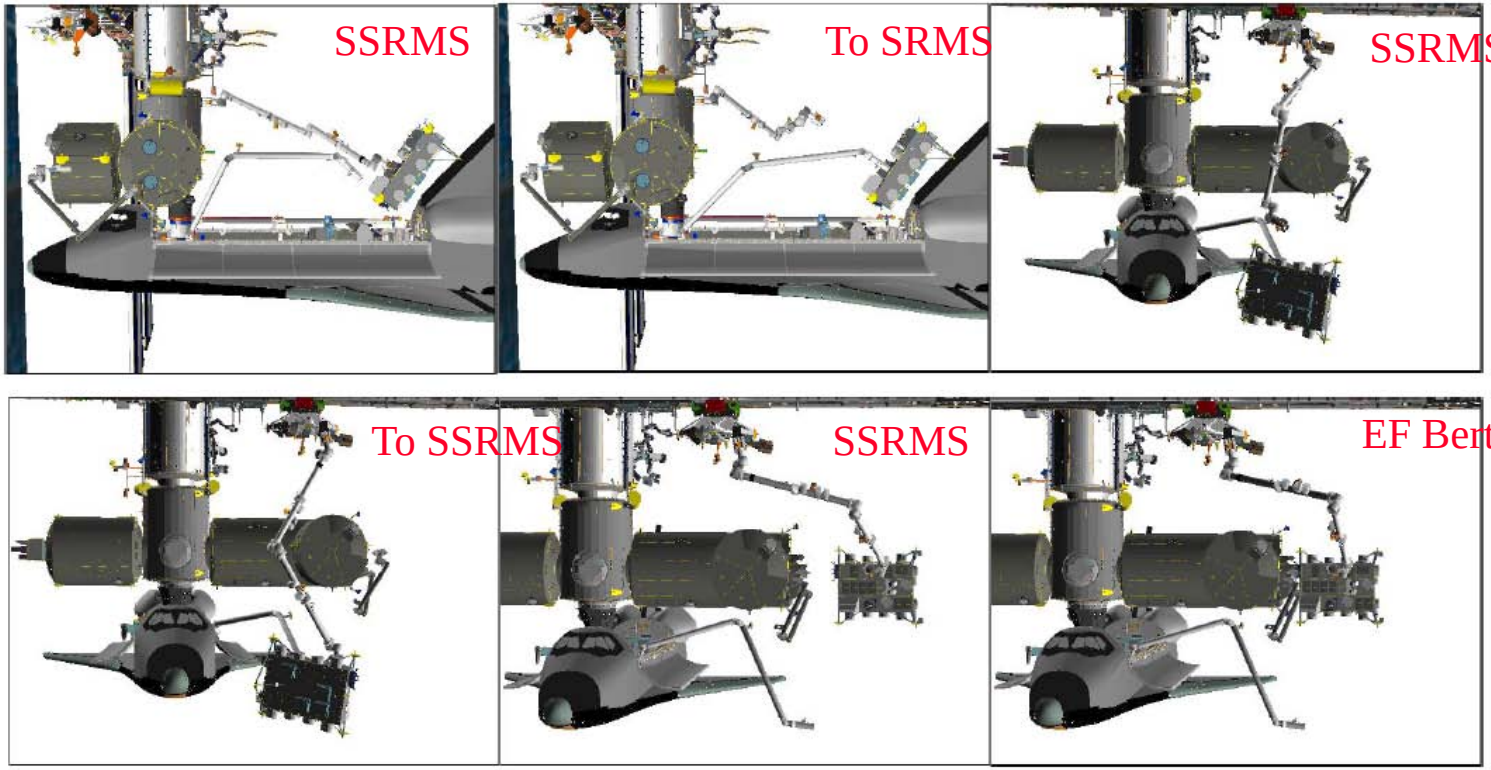
Assembly Sequences of EF

Flight 2J/A

Double Handoff between SSRMS and SRMS
Attach EF to PM (EFBM) by SSRMS

↓

JEMRMS On-orbit Port Location Estimation



Japanese Experiment Module

Assembly Sequences of ELM-ES, HTV-EP and Payloads

Flight 2J/A

Handoff ELM-ES from SRMS to SSRMS
Attach ELM-ES to EF(EFU#10) by SSRMS

↓

Transfer ICS (Sys. P/L) on ES to EF(EFU#7) by JEMRMS
Transfer MAXI (Exp. P/L) on ES to EF(EFU#1) by JEMRMS
Transfer SEDA (Exp. P/L) on ES to EF(EFU#9) by JEMRMS

↓

Handoff ELM-ES from SSRMS to SRMS
Stow ELM-ES to Cargo Bay by SRMS

HTV

Handoff HTV-EP from SSRMS to JEMRMS
Attach HTV-EP to EF(EFU#10) by JEMRMS

↓

Transfer SMILES (Exp. P/L) on EP to EF(EFU#3) by JEMRMS
Transfer HREP(Exp. P/L) on ESPto EF(EFU#6) by JEMRMS

↓

Handoff HTV-EP from JEMRMS to SSRMS
Stow HTV-EP to HTV by SSRMS

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Japanese Experiment Module

Challenges in Berthing Operation (1)
Berthing Operation without EVA

Total 5 crews (IVA/EVA) were planed to require at the EF berthing phase.

EF berthing operations are as follows.

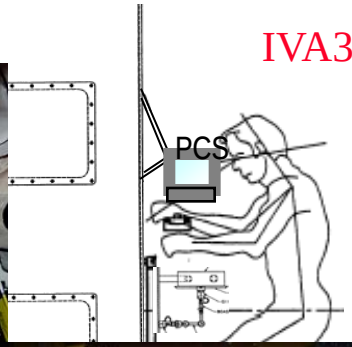
1. IVA1/IVA2(two) crews transfer EF by SSRMS
2. EVA1/EVA2(two) crews guidance EF to RTL* envelop
3. IVA3(one) crew operates EF Berthing Mechanism (EFBM) to capture and retract EF

➔ Berthing Operation without EVA

RTL*: Ready to Latch

IVA1/IVA2

IVA3



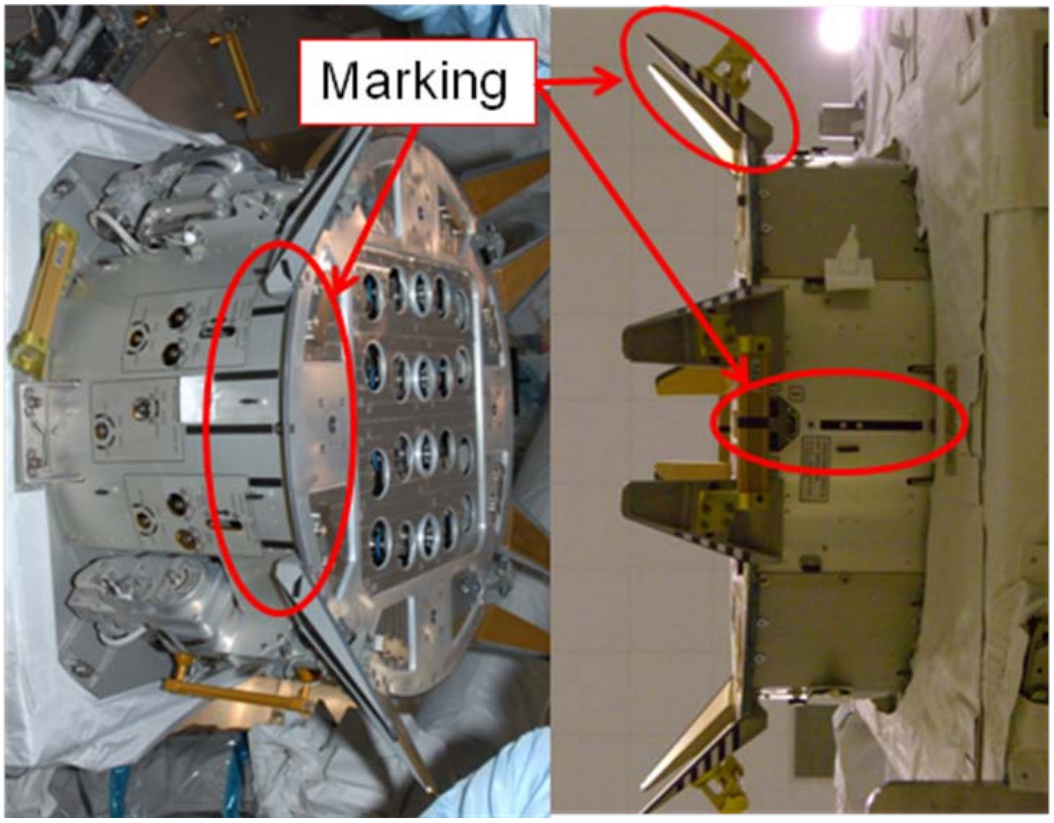
EVA1/EVA2

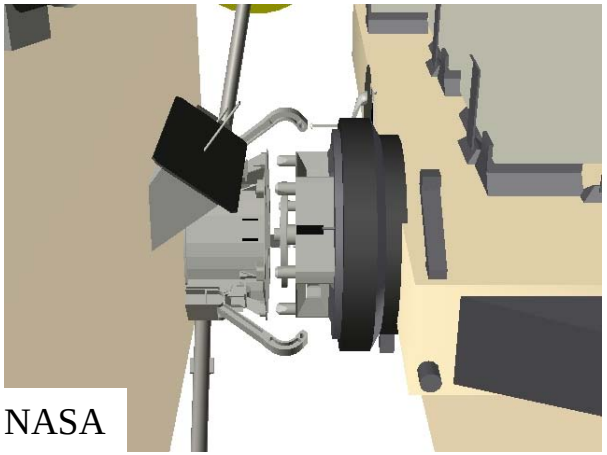
by courtesy of NASA

by courtesy of NASA

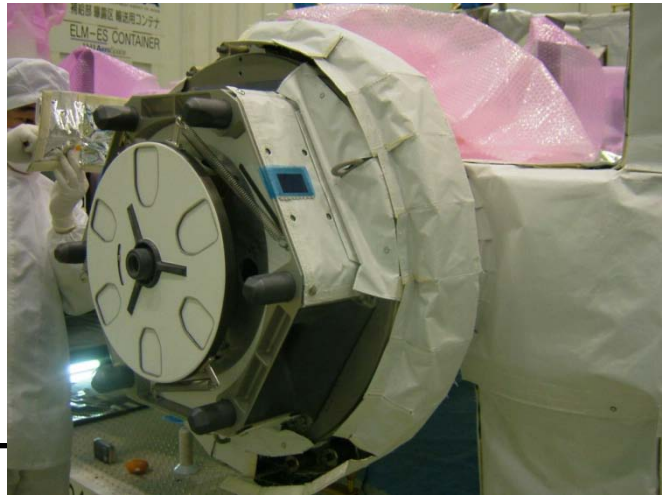
Challenges in Berthing Operation (1)
Berthing Operation without EVA

① Visual Marking on EFBM





NASA

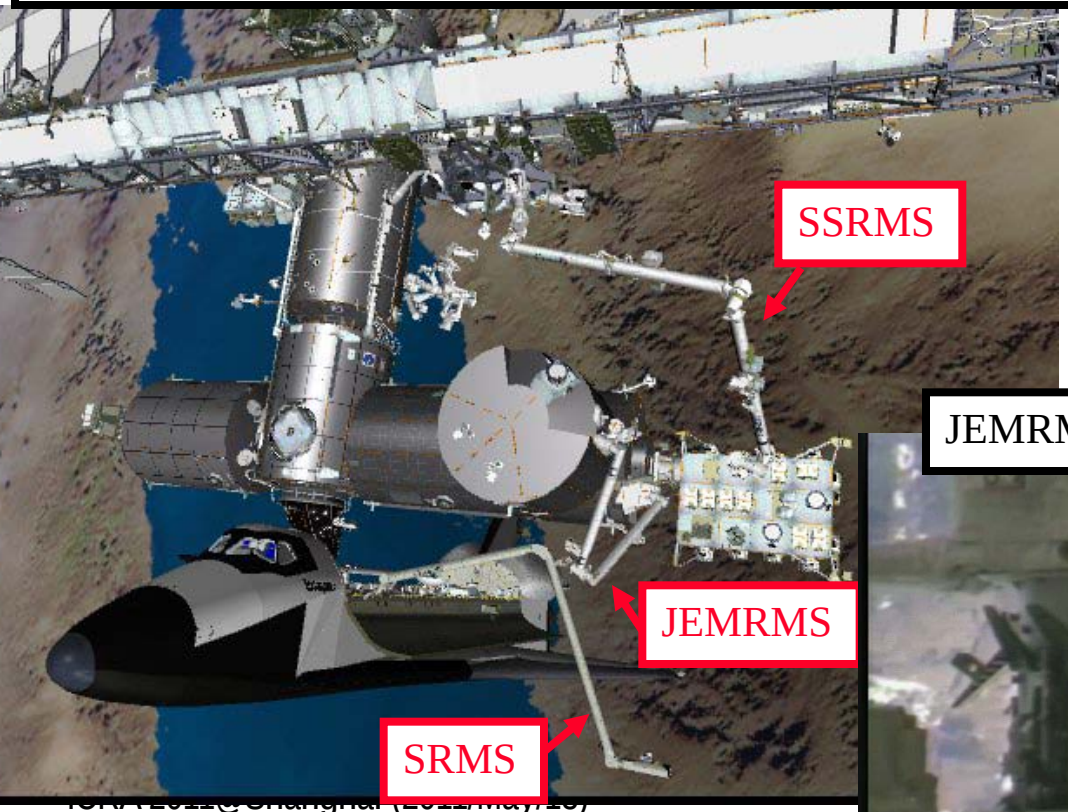


Japanese Experiment Module

Challenges in Berthing Operation (1)
Berthing Operation without EVA

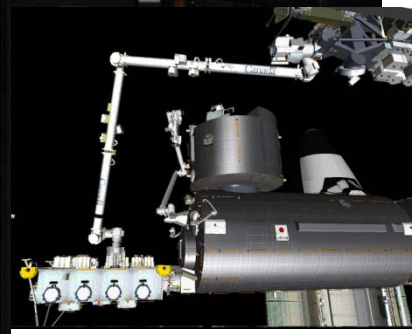
②Simulation Environments were built and Crews Fly the Approach Operation.
(SSRMS Dynamics, Berthing Mechanism（EFBM/EEU）Contact Model, Malfunction of Cameras)

- JEMRMS EE Camera provides excellent view to IVA crew
- The three RMSs (SRMS, SSRMS and JEMRMS) are utilized for EF installation



Crew Evaluation

JEMRMS EE Camera View



by courtesy of NASA

Japanese Experiment Module

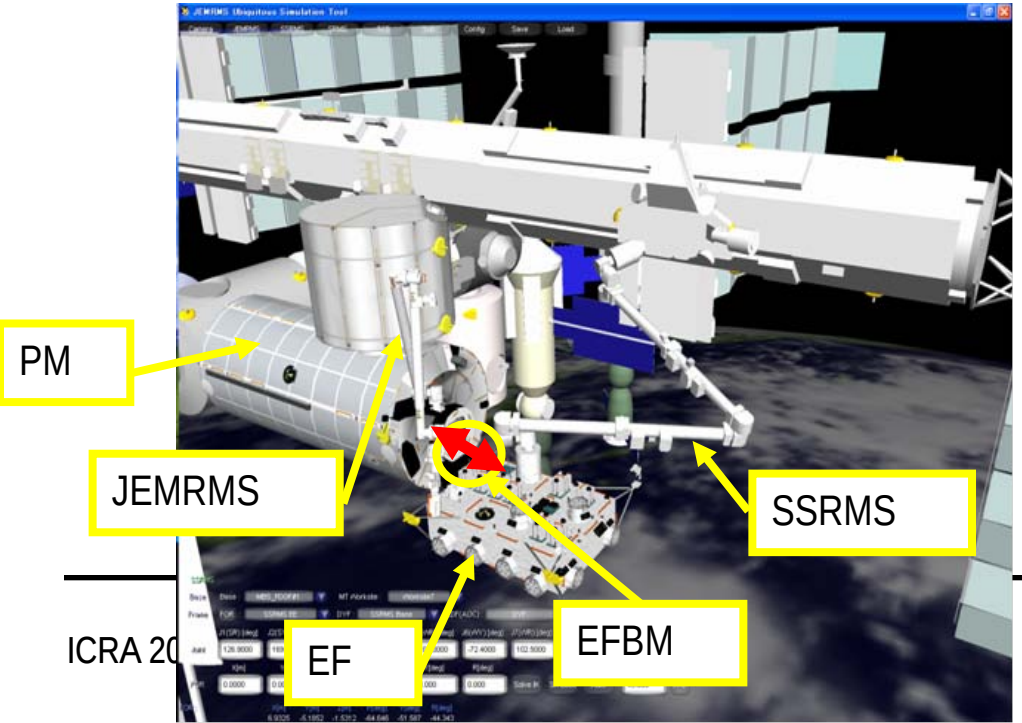
Challenges in Berthing Operation (2)
Force Fight between RMS and Mechanism

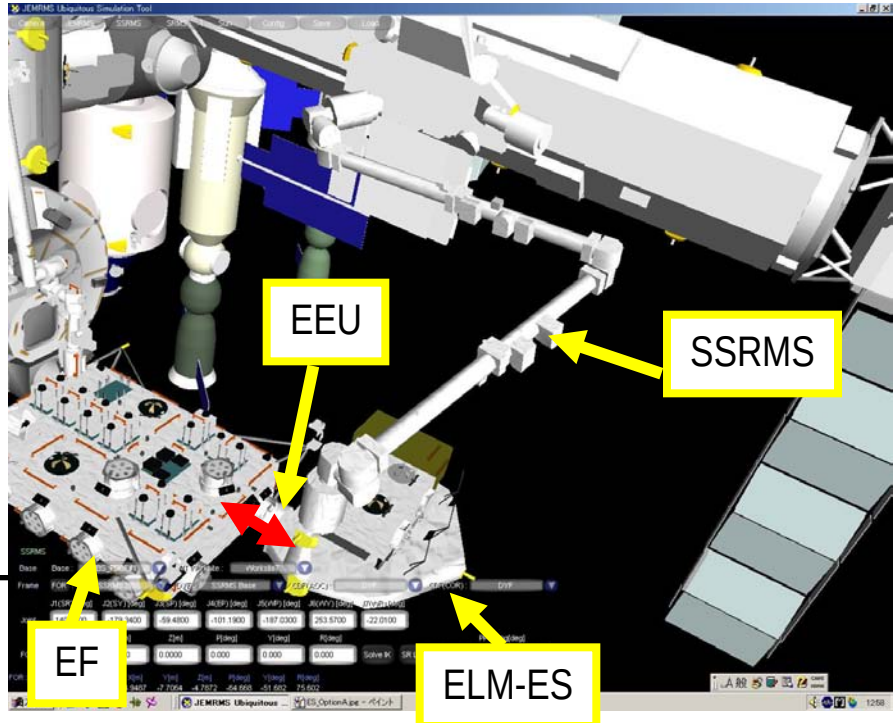
< Force Fight on EF or ELM-ES Berthing >

- Manipulators and berthing mechanism are pulling each other

<Possible Force Fighting Situation>

- When the manipulator is accidentally braked while the mechanism continuously retracts the berthing platform attached to the manipulator.
- When the initial angular misalignments are large and rapidly adjusted by berthing mechanism.





Challenges in Berthing Operation (2)
Force Fight between RMS and Mechanism

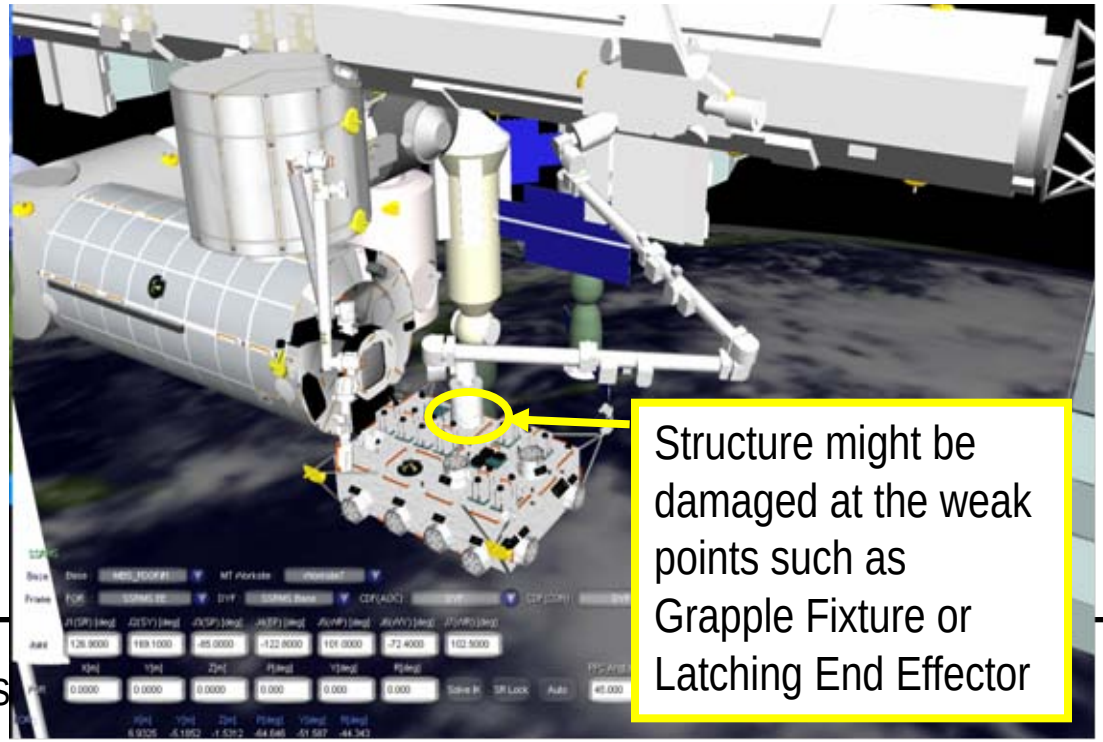
Japanese Experiment Module

Structure might be damaged due to the force fighting

- Safety requirements apply to control and to avoid the force fighting.
- Two Fault Tolerance (2FT) are required for catastrophic hazard*.

Require to indentify the week points

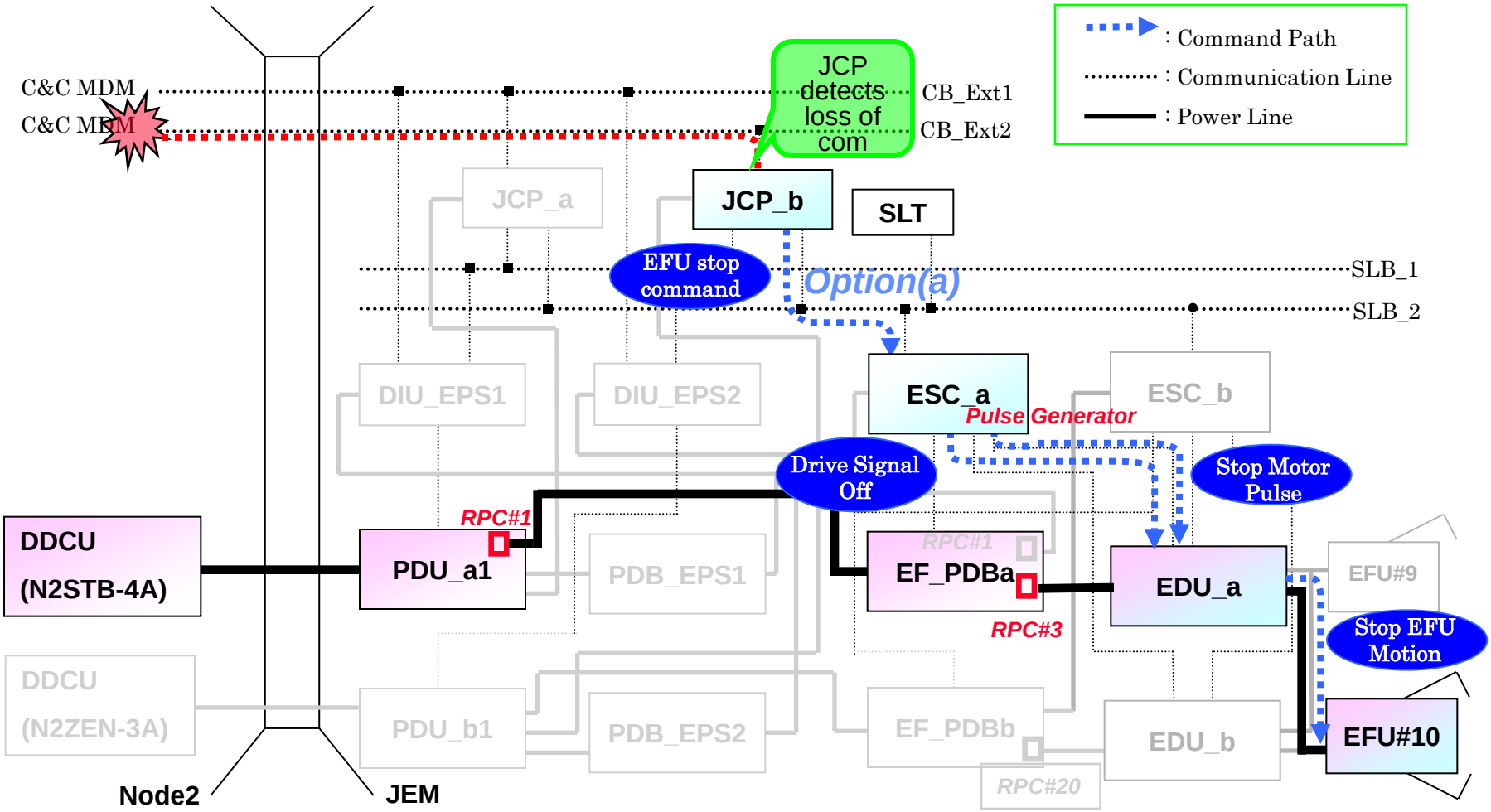
time to load limit and time to stop the mechanism



Catastrophic hazard*:
It may cause disabling or fatal personnel injury, or cause loss of ISS, the orbiter and major ground facility.

Japanese Experiment Module

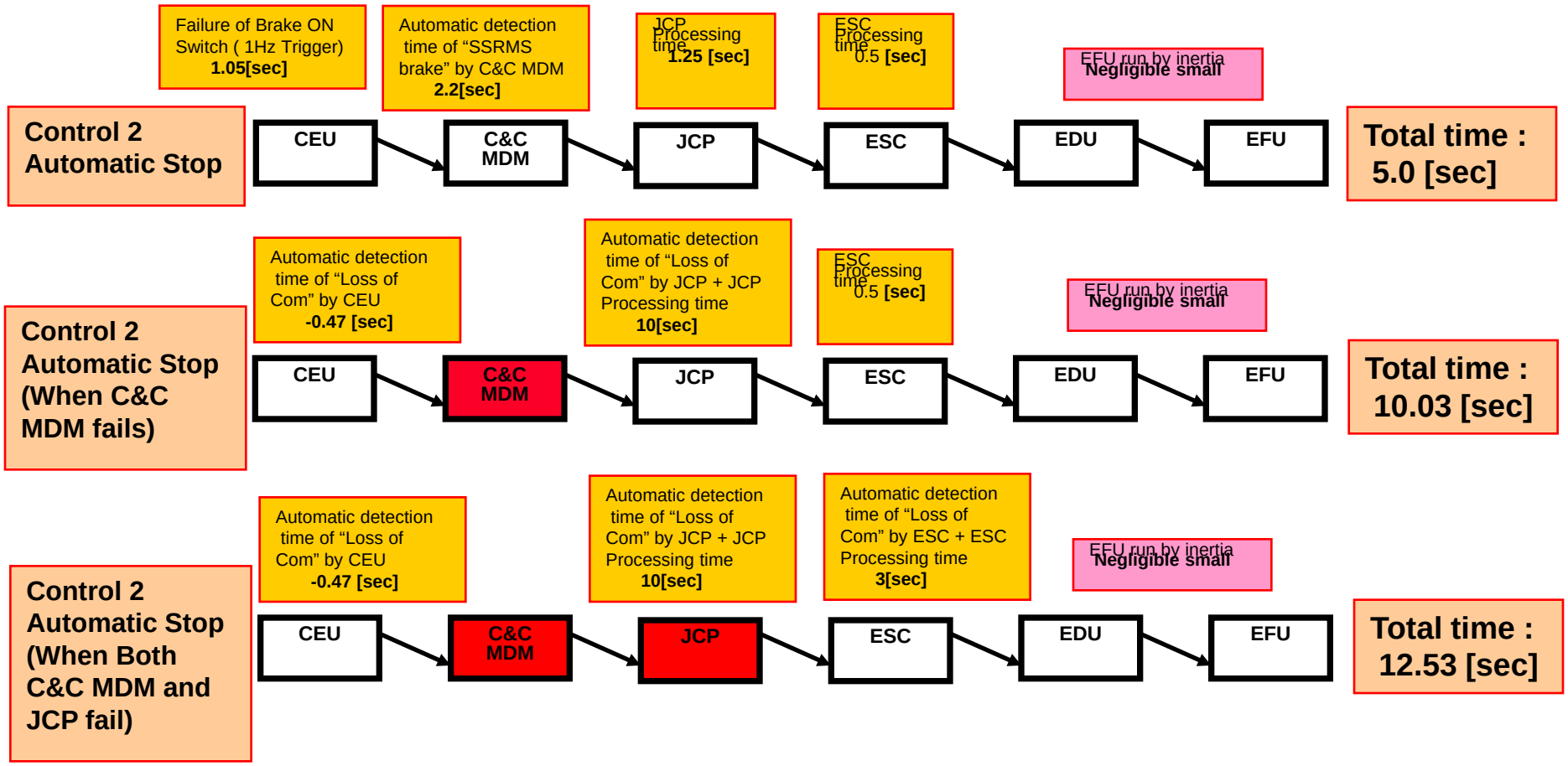
Automated EFU Stop : Command from JCP



Power & Communication System Schematics (EEU Operation Related)

Japanese Experiment Module

Prediction Time to Stop Mechanism



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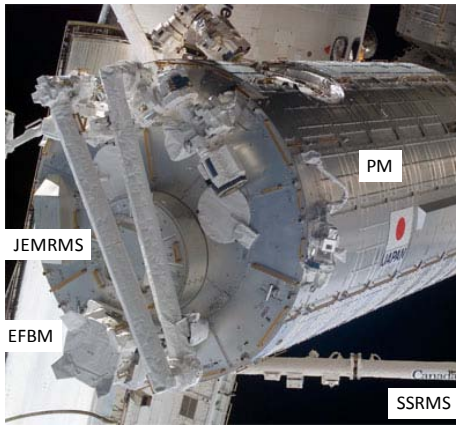
JEMRMS Initial Checkout

The objectives of initial checkout are

To confirm the essential functions needed to operate JEMRMS

To acquire on-orbit data to identify the characteristics of JEMRMS.



(1) Essential function checkout [mode transition, auto procedure, grasping ops]

(2) Safety critical function checkout [E-stops, braking performance]

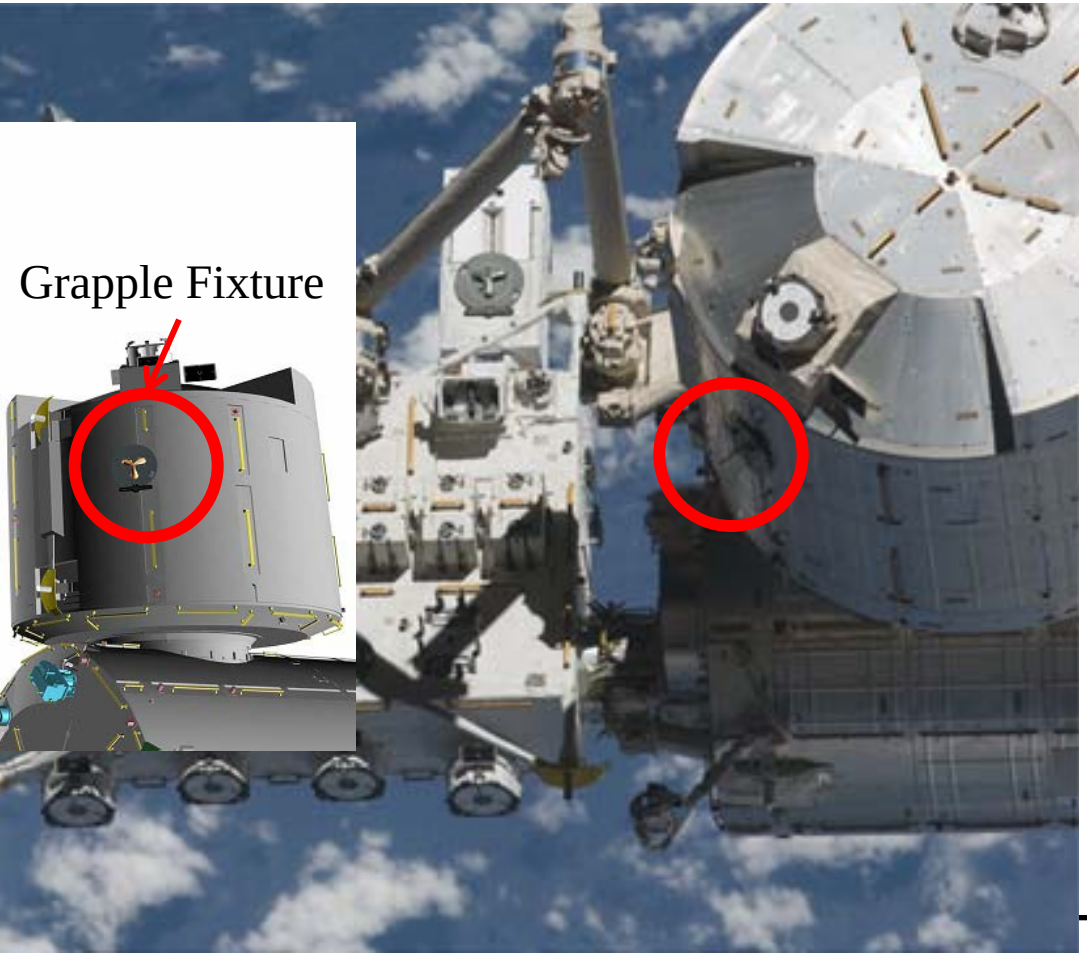
(3) Data acquisition [dynamic characteristics]

by courtesy of NASA

Japanese Experiment Module

Grapple Fixture Grasping

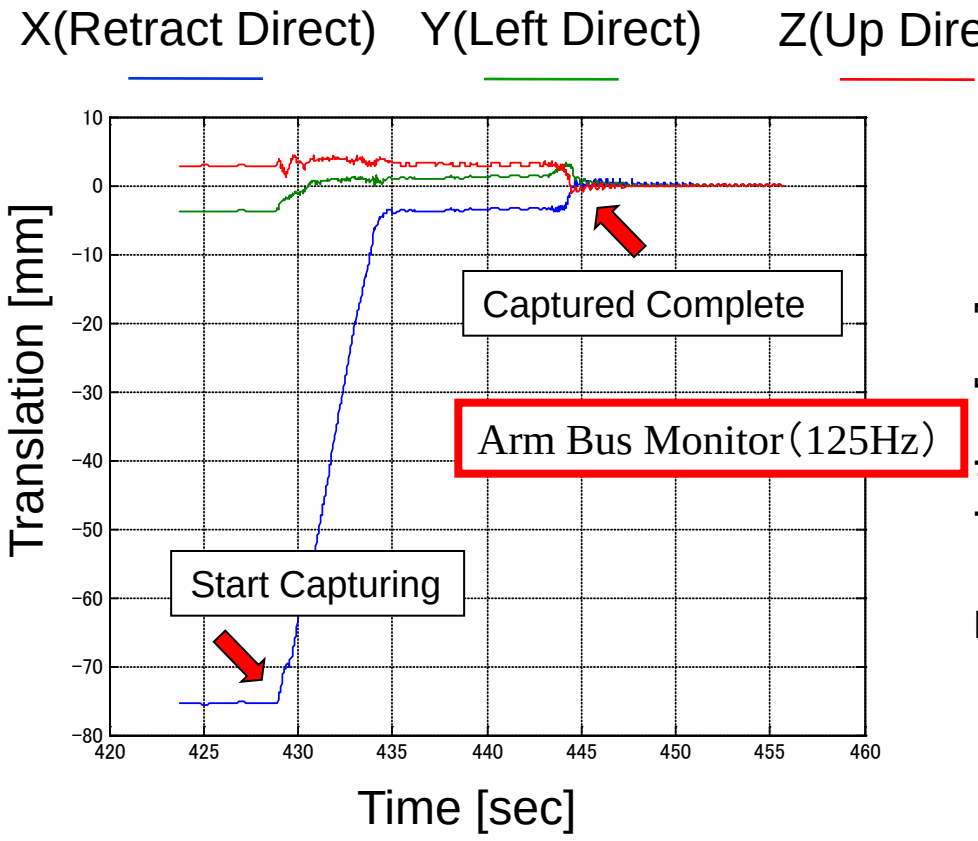
The grapple fixture operation has been performed by utilizing the grapple fixture on JEM-PS.

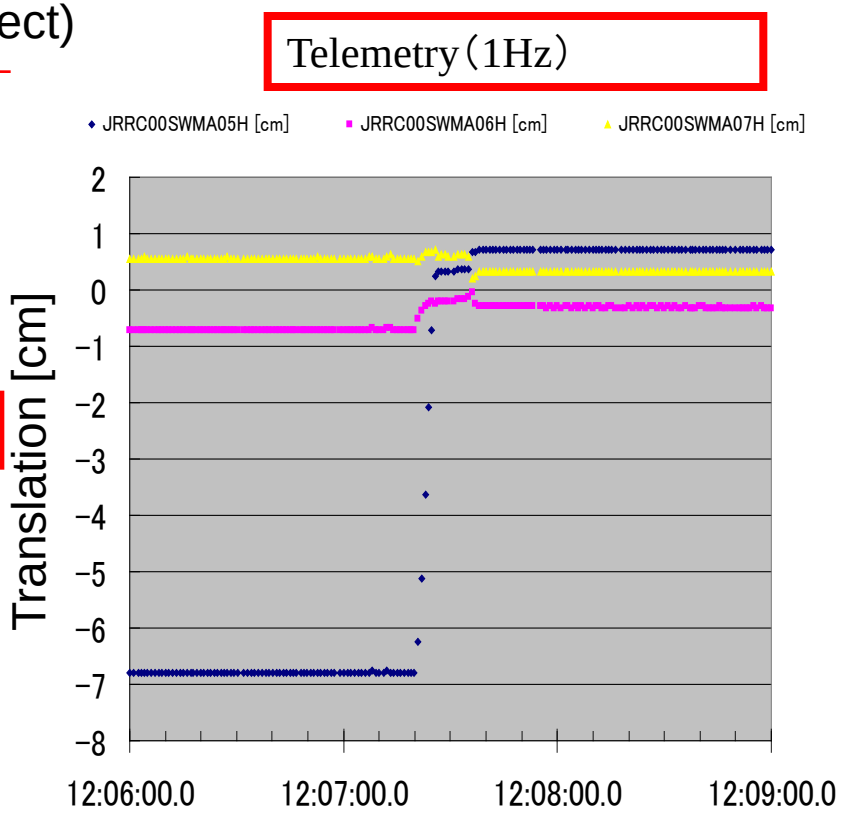


by courtesy of NASA

Joint Limp (back-Drive) Characteristics

Arm Mode: Limp (Brake-off)

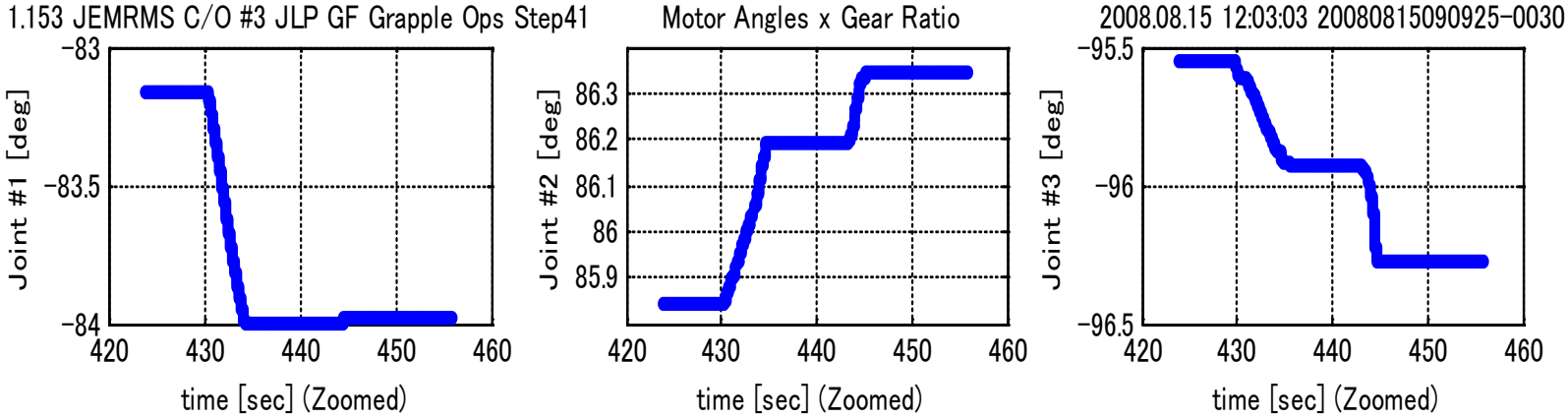




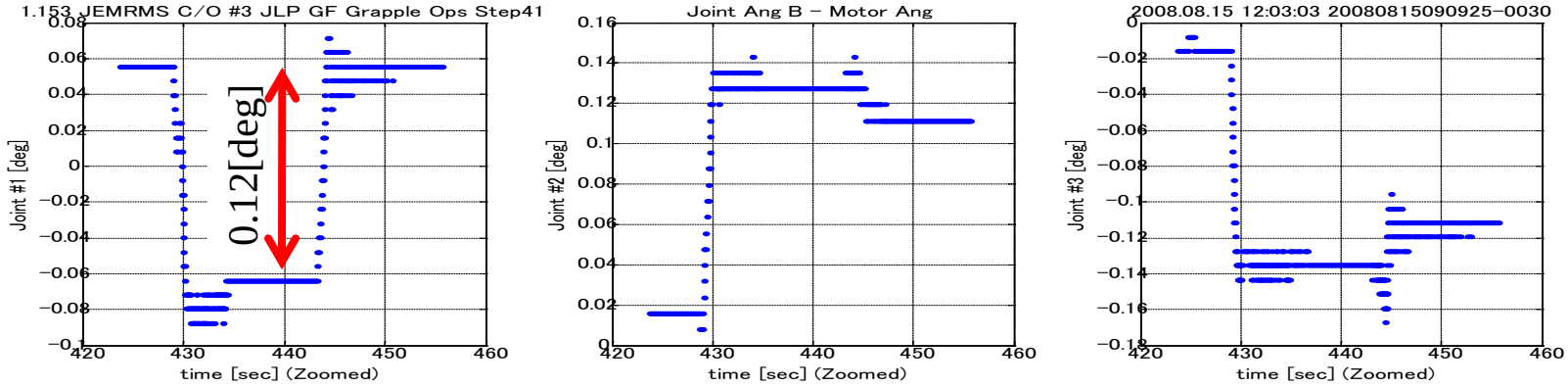
Japanese Experiment Module

Joint Limp (back-Drive) Characteristics

Joint Behavior During Limp Motion

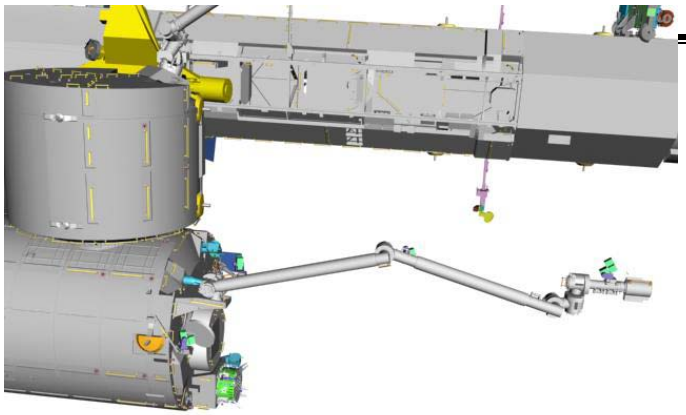


Joint Behavior Difference between Motor and Joint



Japanese Experiment Module

Dynamics Characteristics



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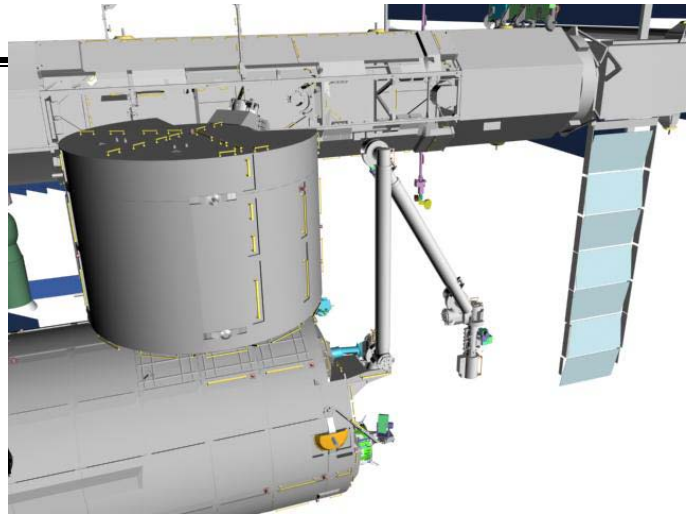
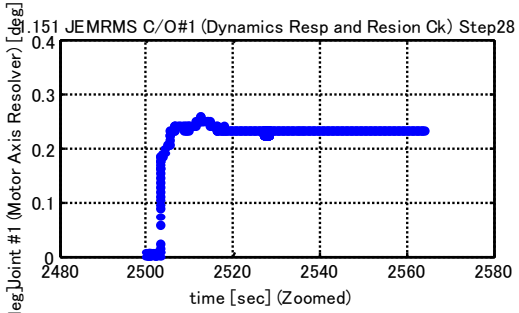
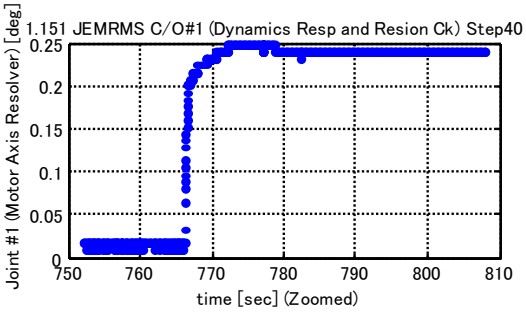
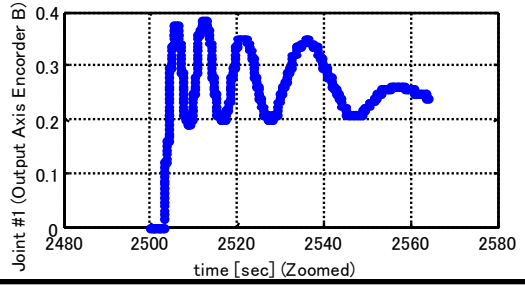


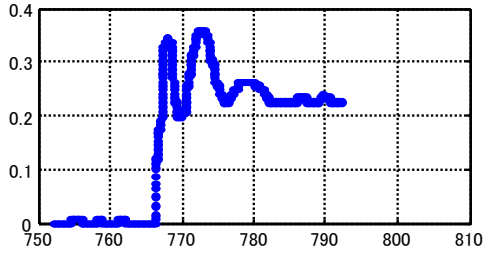
Motor Axis



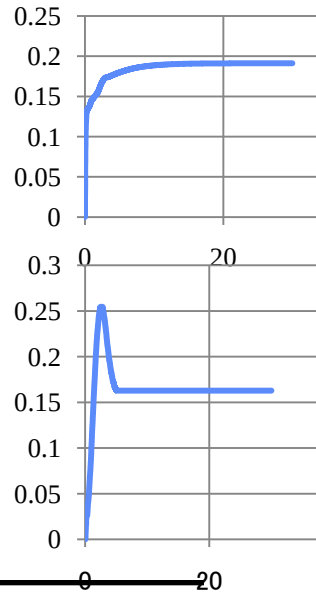


Output Axis





Analysis (Extended)



ICRA 2011@Shanghai (2011/May/13)

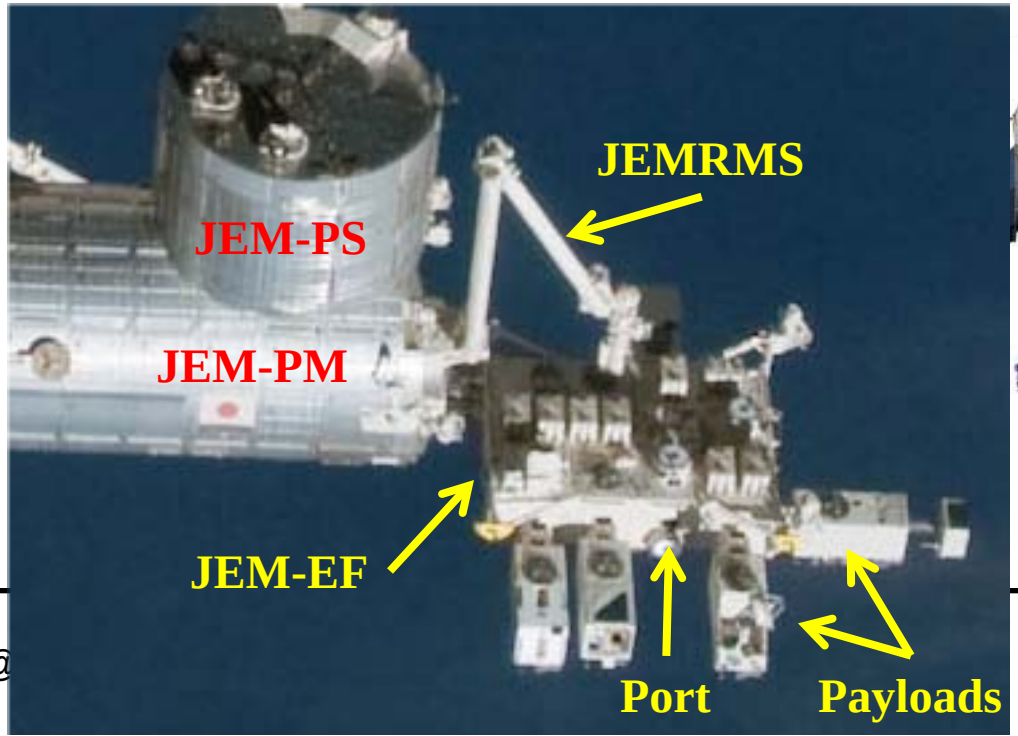
Outline

1. Japanese Experiment Module ’Kibo’
2. Assembly Sequences of JEM
3. Berthing Operation Consideration of EF, ES
4. Initial Checkout of JEMRMS
5. Berthing Operation by JEMRMS

Japanese Experiment Module

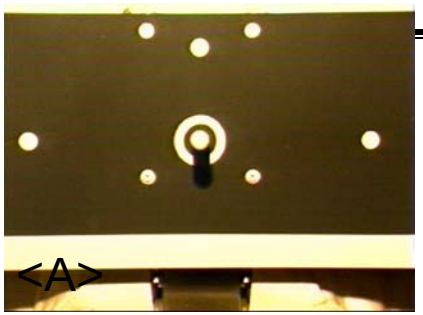
Port Location Estimation Camera Calibration

- The measurement of port location on-orbit to precisely position for the berthing operation.
- The wrist camera calibration to confirm that the parameters are maintained on orbit.
- The wrist camera parameters to obtain on the ground test

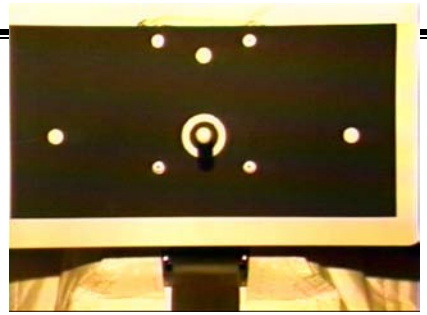


Japanese Experiment Module

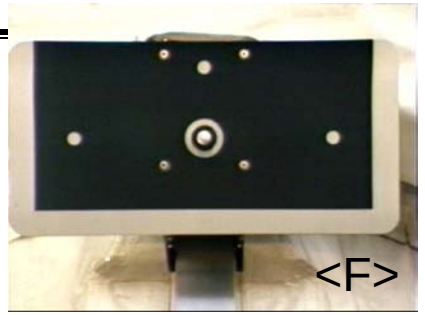
On-orbit Camera Calibration



Approach +150mm



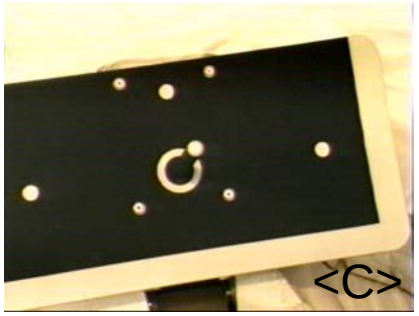
Reference



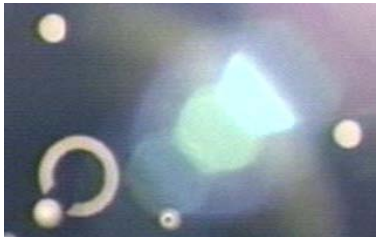
Approach -150mm

Direct Sunlight on Rod Tip

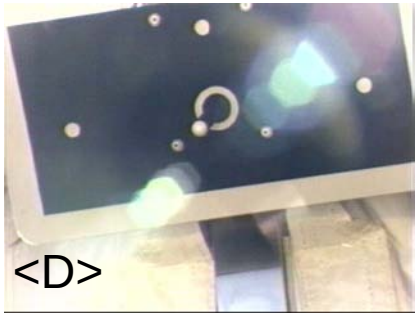
Rod Tip at <E>

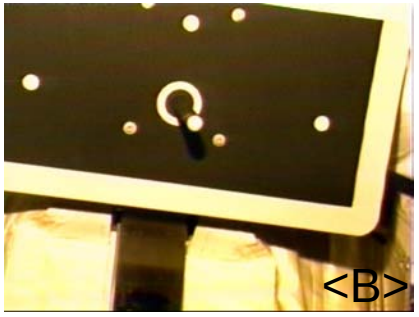


Sunlight Refection into Camera



Refection at <D>



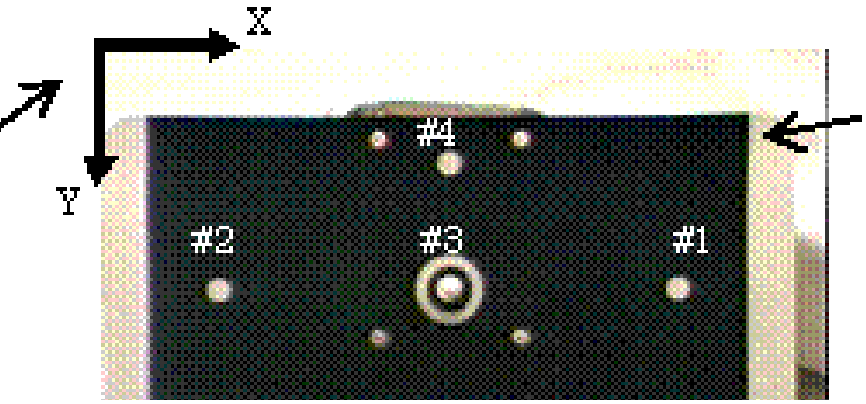


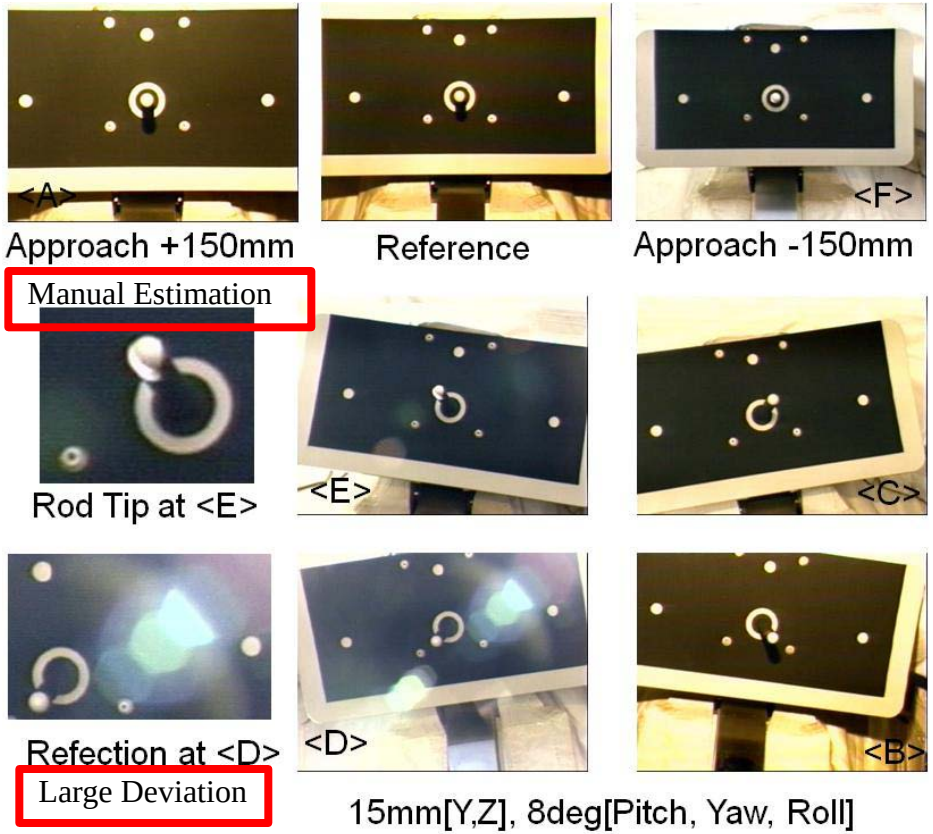
15mm[Y,Z], 8deg[Pitch, Yaw, Roll]

On-orbit Camera Calibration

Japanese Experiment Module

- By neglecting location ‘E’, the estimation errors become the smallest.
- The parameters estimated on orbit are similar to ones of the ground.





Arm Config	Image Number	Mark Center Location Standard Deviation[pixel]								
		Mark 1 X	Mark 1 Y	Mark 2 X	Mark 2 Y	Mark 3 X	Mark 3 Y	Mark 4 X	Mark 4 Y	RSS
BERTH POS	10	0.2885	0.5839	0.3386	0.5858	0.3949	0.6418	0.3467	0.5427	1.3655
CAL A	10	0.1628	0.3380	0.2061	0.3627	0.2145	0.3626	0.1789	0.3573	0.8075
CAL B	10	0.4239	0.7510	0.5124	0.7575	0.4663	0.7875	0.4585	0.8222	1.8177
CAL C	11	0.2951	0.7383	0.2789	0.7638	0.3444	0.7578	0.2973	0.7392	1.6190
CAL D	10	0.4447	1.1039	0.4021	1.0882	0.4736	1.1691	0.4888	1.1136	2.4150
CAL E(*1)	10	0.3797	0.5543	0.3358	0.4515	0.3157	0.4394	0.3608	0.4587	1.1838
CAL F	10	0.2077	0.6651	0.2047	0.7029	0.2225	0.7425	0.1659	0.6555	1.4420

IC

Japanese Experiment Module

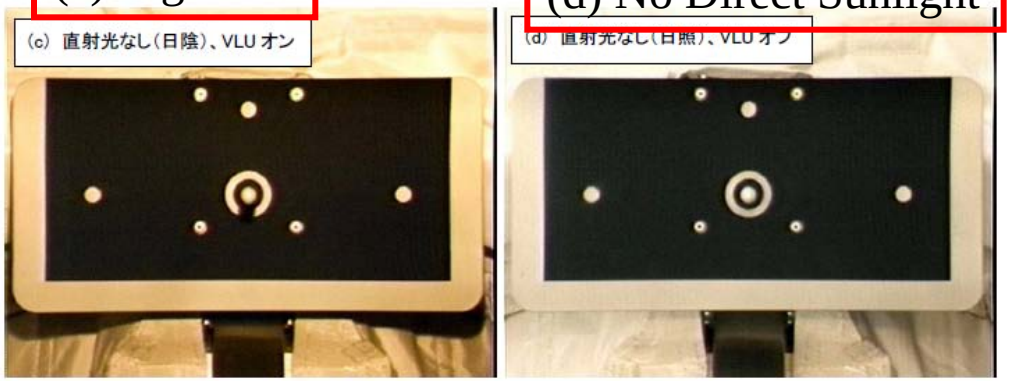
Long Term Effect of Camera/Target

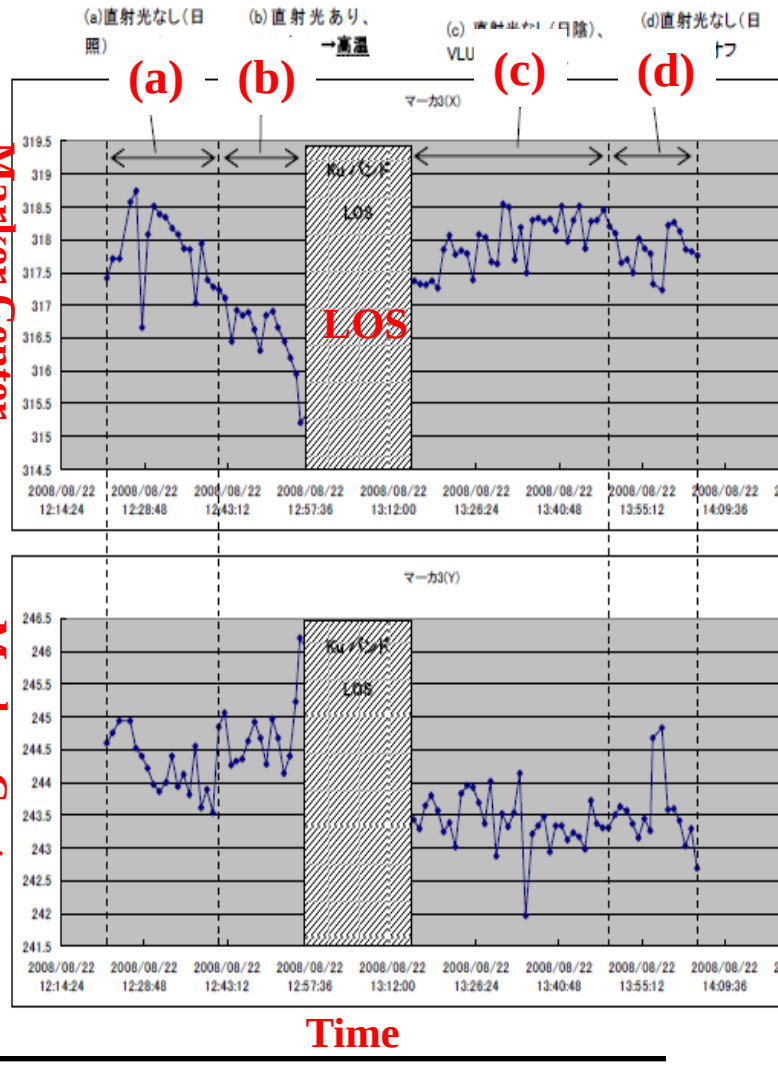
(a) No Direct Sunlight

(b) Direct Sunlight

(c) Light On

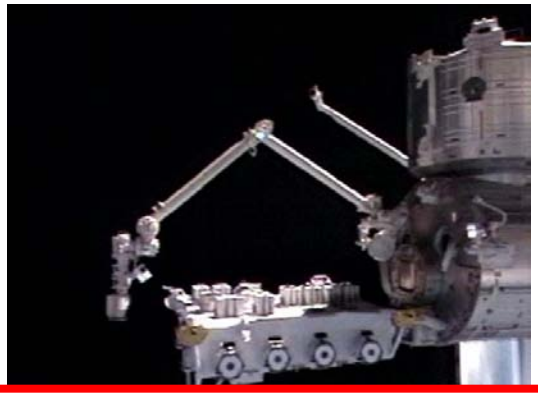
(d) No Direct Sunlight



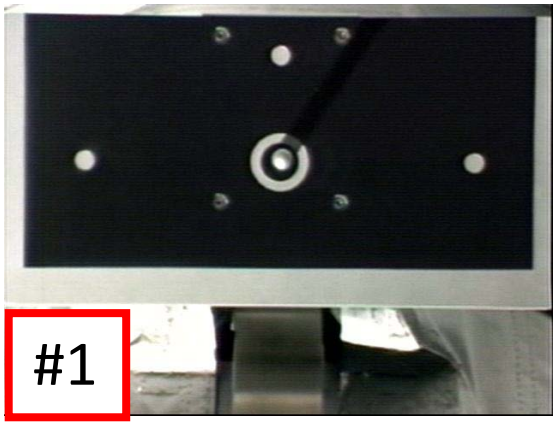


Japanese Experiment Module

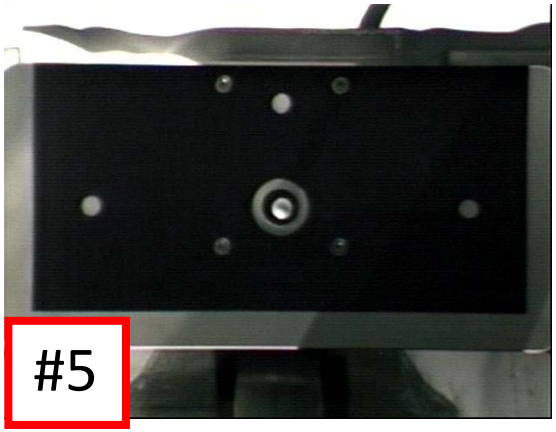
Port Location Estimation



Port Location Estimation on #9



#1



#5

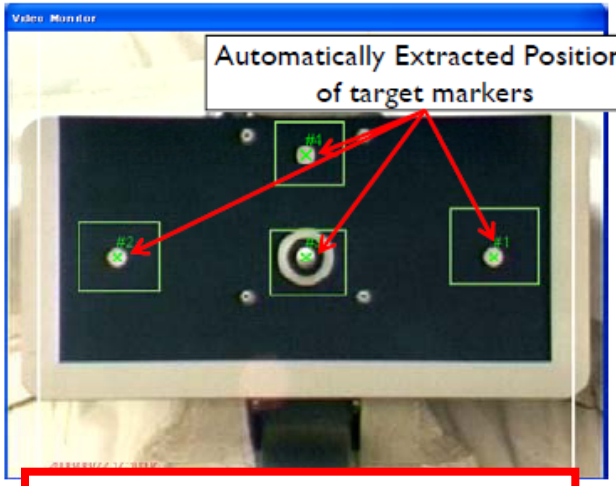
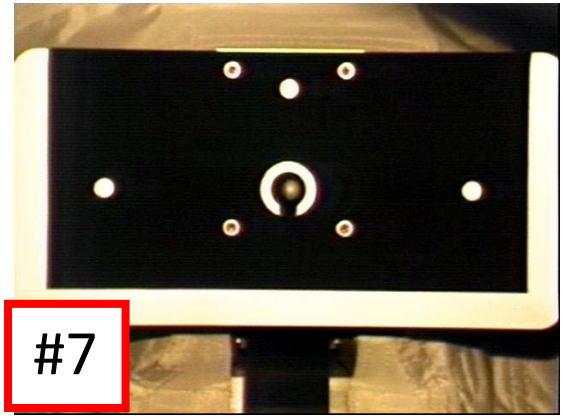
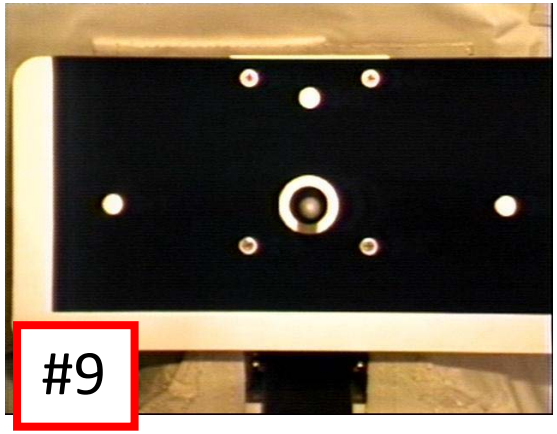


Image Processing On Ground



#7



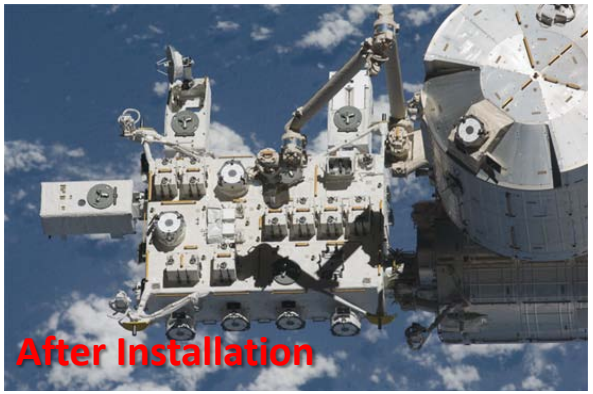
#9

Japanese Experiment Module

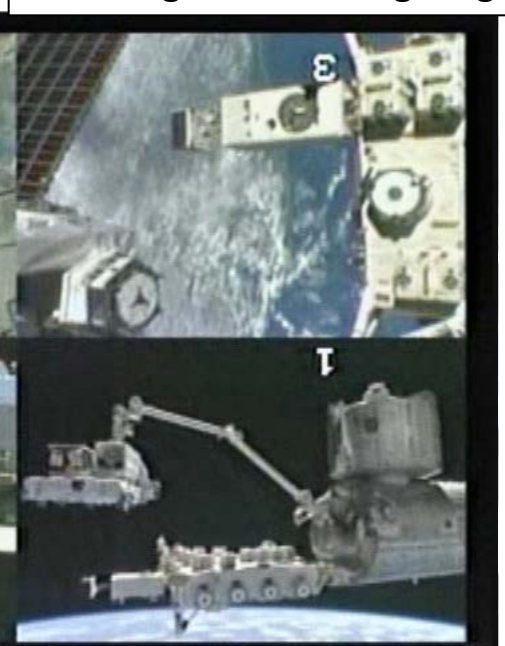
Payload Berthing by Kibo Robot Arm

Three Payloads were assembled by Astronauts tele-operation. (July '09)

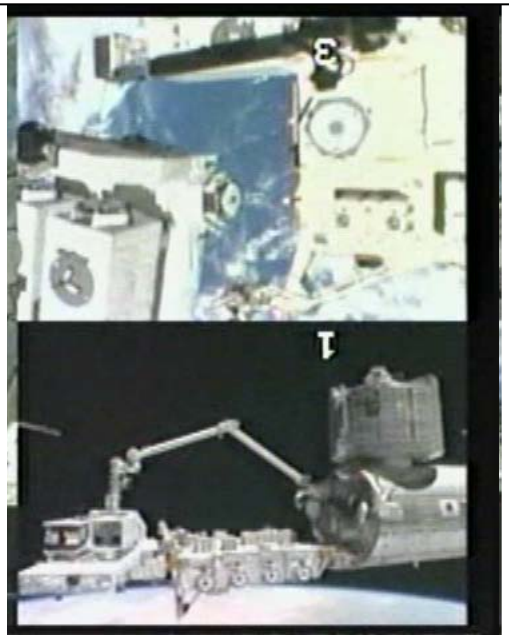
Standard Payload Specification
- Mass: 500kg
- Shape: 0.8 x 1.0 x 1.8 m
- Interface Function
  - Robot Arm
  - Equipment Exchange Unit



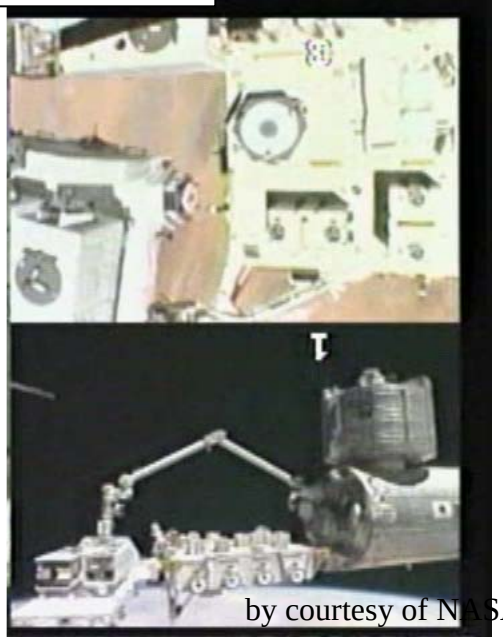
Handling and Berthing Large Size Pallet (2300kg) were also successful . (Sept'09 , Feb '11)



Handling EP



Positioning EP

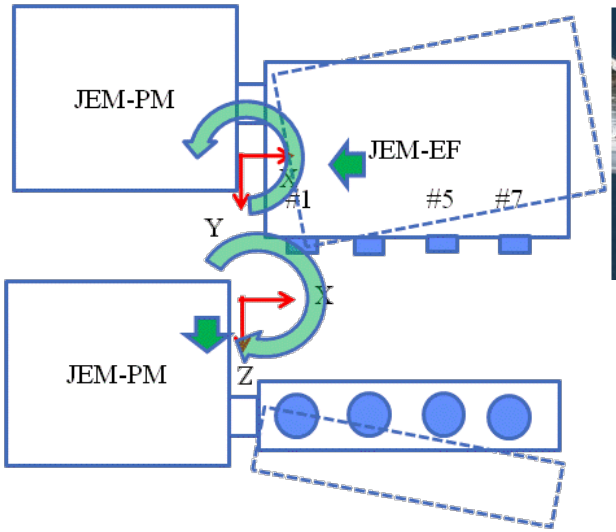


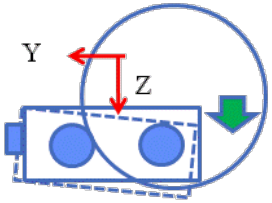
by courtesy of NASA

Japanese Experiment Module

JEMRMS Base Offset

- Estimate the base offset from the location of five ports
- Find the base offset to be the pressurized deformation and zero-gravity effect.



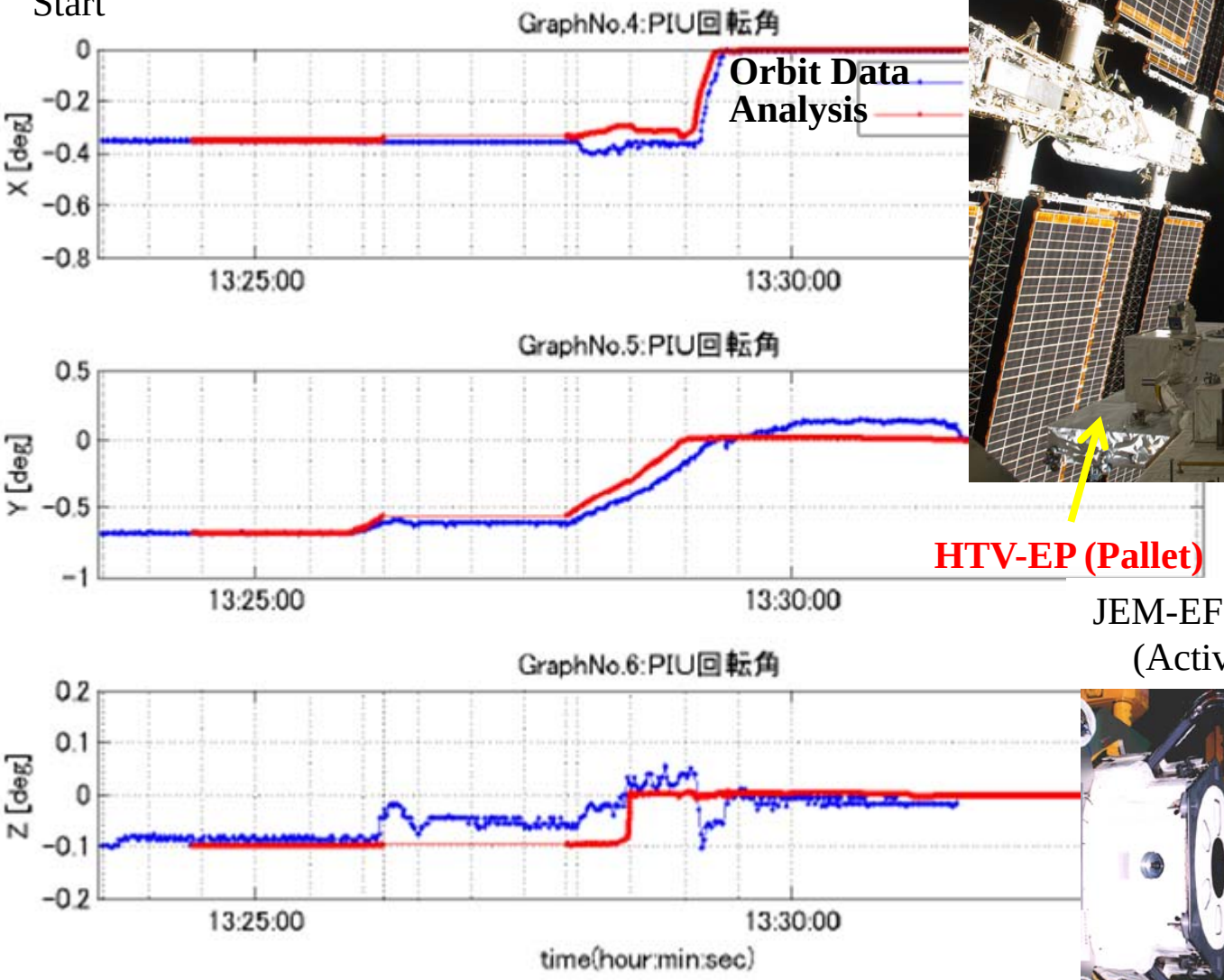


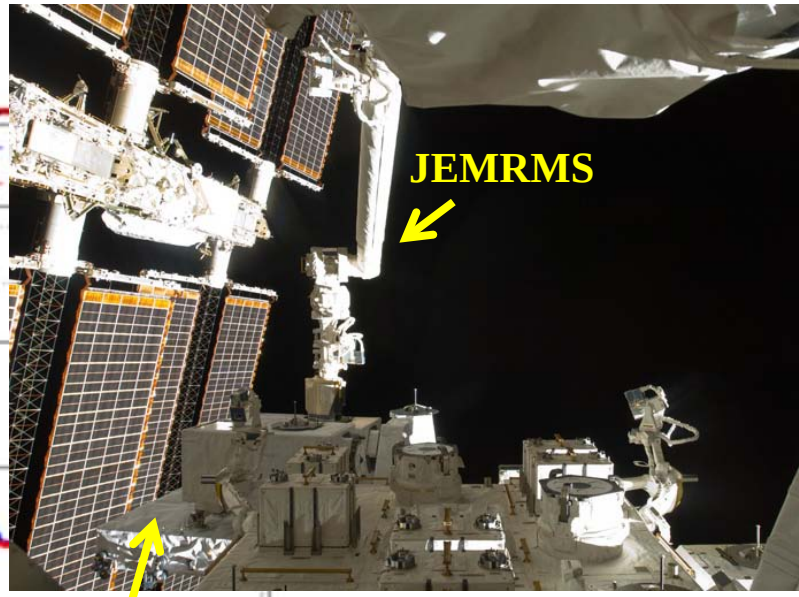
	EF Coordinates@RMS Coordinates					
	X[mm]	Y[mm]	Z[mm]	R[deg]	P[deg]	Y[deg]
Design	−20.3	−9.6	22.3	−0.02	−0.71	−0.37
Estimated Error	2.5	1.6	3.9	0.00	0.08	0.06
Max in Design	−22.8	−11.1	18.5	−0.02	−0.79	−0.43
Min in Design	−17.7	−8.0	26.2	−0.02	−0.63	−0.31
Estimated Offset	−28.1	−6.3	16.8	0.15	−0.75	−0.53
Difference	5.3	1.8	1.6	0.17	○	0.10

Japanese Experiment Module

JEMRMS Berthing Data

Start





by courtesy of NASA

JEM-EF Side (Active)

Payload Side (Passive)